Article

Discovery Medicine 2025; 37(203): 2942–2951
https://doi.org/10.24976/Discov.Med.202537203.246

Association Between the Triglyceride-glucose-body Mass Index and Acute Kidney Injury Following Cardiac Surgery Under Cardiopulmonary Bypass: A Retrospective Cohort Study

Pingxiong Zeng[1,†], Yingling Zhong[1,†], Weichang Wang[1], Jingdan Deng[1], Weixiong Lin[1,*]

[1]Department of Anesthesiology, Meizhou People's Hospital, 514031 Meizhou, Guangdong, China
*Correspondence: weixionglin2026@163.com (Weixiong Lin)
[†]These authors contributed equally.
Submitted: 7 October 2025 Revised: 31 October 2025 Accepted: 10 November 2025 Published: 20 December 2025

Background: Cardiac surgery-associated acute kidney injury (CSA-AKI) is a common condition, posing significant morbidity and mortality. Combined triglyceride-glucose (TyG) index-body mass index (BMI) may offer enhanced predictive performance for CSA-AKI compared to TyG or BMI alone. Therefore, this study aims to assess whether the preoperative TyG-BMI index outperforms individual TyG or BMI measurements in predicting CSA-AKI.

Methods: This retrospective cohort study included adult patients (n = 652) undergoing cardiac surgery with cardiopulmonary bypass (CPB). The TyG-BMI was calculated as ln[triglyceride (mg/dL) × fasting glucose (mg/dL)/2] × BMI (kg/m^2) and CSA-AKI was defined according to Kidney Disease: Improving Global Outcomes (KDIGO) criteria. The discriminative performance of combined TyG-BMI and individual TyG and BMI was compared using receiver operating characteristic (ROC) analysis. These three indicators were incorporated independently into a baseline predictive model, and model performance was examined. Multivariable logistic regression and restricted cubic splines (RCS) were applied to evaluate the association between TyG-BMI and CSA-AKI. Subgroup analyses were performed to assess effect heterogeneity by age, sex, hypertension, diabetes, and other comorbidities.

Results: Among the study cohort (n = 652), CSA-AKI was reported in 34.4% (224/652) of the cases. TyG-BMI showed superior discriminative performance compared to TyG or BMI alone (AUC: 0.712 vs. 0.666 and 0.681; DeLong test $p = 0.021$ and <0.001, respectively). Incorporating TyG-BMI, TyG, and BMI into the baseline prediction model (AUC: 0.773) increased the AUC to 0.814 for TyG-BMI, 0.794 for TyG, and 0.805 for BMI. RCS indicated a linear association between TyG-BMI and CSA-AKI (p for nonlinearity = 0.496). For every 15-unit increase in TyG-BMI, the risk of CSA-AKI increased by 41% (adjusted OR: 1.41, 95% CI 1.28–1.55; $p < 0.001$). Patients in the highest TyG-BMI quartile had significantly higher odds of CSA-AKI (adjusted OR: 5.00; 95% CI 2.68–9.35; $p < 0.001$) compared to those in the lowest quartile. Subgroup analyses confirmed these findings, except in those with diabetes ($p = 0.279$).

Conclusions: Preoperative TyG-BMI is independently associated with CSA-AKI in a linear dose-response manner. As a cost-effective composite marker of insulin resistance and adiposity, TyG-BMI improves preoperative risk stratification and enables targeted interventions to mitigate postoperative renal injury. Prospective studies are needed to further validate its clinical applicability.

Clinical Trial Registration: Chinese Clinical Trial Registry (ChiCTR2500103685).

Keywords: cardiac surgery; triglyceride; glucose; body mass index; acute kidney injury

Introduction

Acute kidney injury (AKI) is a prevalent complication following cardiac surgery, with cardiac surgery-associated AKI (CSA-AKI) reported in approximately 30% to 40% of cases, depending on the diagnostic criteria applied [1,2]. Multiple predisposing and intraoperative factors, including preoperative obesity, hyperglycemia, longer cardiopulmonary bypass (CPB) duration, persistent intraoperative hypotension, and systemic inflammation, are associated with its development [3,4]. Patients with CSA-AKI experience a significantly higher mortality risk compared to those without this condition [5], and they are at potential risk of persistent renal dysfunction and broader systemic complications, ultimately leading to increased mortality [6]. The pathophysiology of CSA-AKI is multifactorial, involving inflammation, oxidative stress, renal hypoperfusion, and ischemia-reperfusion injury [7,8]. Currently, there are no specific treatments, which makes prevention the most viable strategy for mitigating CSA-AKI's impact [4]. Preop-

erative risk stratification to identify high-risk individuals, along with early perioperative interventions, is crucial to alleviating the risk of postoperative AKI [9,10].

Increased preoperative Triglyceride-glucose (TyG) index [11] and body mass index (BMI) are both associated with a higher risk of CSA-AKI [12]. An elevated TyG index is strongly correlated with chronic microvascular injury and renal microcirculatory dysfunction [12,13], and higher TyG levels following coronary revascularization are significantly linked to AKI risk [14]. Obesity is a well-established risk factor for perioperative AKI in both non-cardiac and cardiac surgical settings [12,15]. Notably, the link between the TyG index and chronic kidney disease (CKD) appears to be independent of gender and obesity status [16]. Clinically, a subset of patients with normal BMI experience triglyceride abnormalities, indicating that BMI alone does not adequately capture underlying lipid and glucose metabolic disruptions and may not directly correspond to an elevated AKI risk [17].

Previous research evidence involving mixed metabolic states, such as normal BMI with elevated TyG or normal TyG with elevated BMI, remains inadequate. The novel TyG-BMI index offers a more robust measure of insulin resistance (IR) [18] by integrating IR and adiposity, which are key determinants of AKI risk [19,20]. Compared to TyG or BMI alone, TyG-BMI may demonstrate a stronger association with CSA-AKI. However, current evidence regarding the association between TyG-BMI and CSA-AKI remains limited.

This retrospective study aims to assess whether the preoperative TyG-BMI index outperforms individual TyG or BMI measurements in predicting CSA-AKI, thereby providing clinicians a concise and effective tool for preoperative risk stratification and addressing existing research gaps. We hypothesize that elevated preoperative TyG-BMI values are independently correlated with a higher risk of CSA-AKI and enhance the discriminative performance of existing predictive models.

Methods

Study Design and Ethical Considerations

This retrospective cohort study was conducted at Meizhou People's Hospital, China, and the study design was approved by the Ethics Committee of Meizhou People's Hospital (Approval No.: 2025-C-18). Given the retrospective study design and anonymized data, the ethics committee waived the requirement for individual informed consent. We registered this study with Chinese Clinical Trial Registry (ChiCTR2500103685, https://www.chictr.org.cn/showproj.html?proj=270493, 4 June 2025) and conducted it in compliance with the principles of the Declaration of Helsinki. Data were sourced from the hospital's Clinical Data Center, including electronic medical records, anesthesia and surgical records, prescription databases, and laboratory assessment information systems. Access to these records and databases was authorized by the Department of Medical Administration and the Department of Medical Data.

Inclusion-Exclusion Criteria for Study Participants

Patients aged 18 years and above and those undergoing cardiac surgery with CPB were enrolled in this study. However, they were excluded from the study cohort if any of the following features were observed: (1) missing preoperative data on fasting glucose, triglycerides, or BMI, (2) preoperative uremia, (3) unavailability of serum creatinine (Scr) measurements within 7 days after surgery or (4) without available medical records.

Data Collection

Data extraction and cleaning were conducted following standardized research protocols. Patient-related information was de-identified in accordance with institutional data protection policies. Demographic variables included age, sex, and BMI. Recorded comorbidities included hypertension, diabetes, coronary heart disease (CHD), and hyperuricemia. Laboratory parameters included albumin, low-density lipoprotein cholesterol (LDL-C), serum creatinine (Scr), estimated glomerular filtration rate (eGFR), blood urea nitrogen (BUN), triglycerides, glucose, hemoglobin, and high-density lipoprotein cholesterol (HDL-C).

Furthermore, left ventricular ejection fraction (LVEF) and coronary angiography findings were also recorded preoperatively. Preoperative medication use included antihypertensive, lipid-lowering, anti-diabetic, and diuretic agents. Intraoperative and perioperative indicators included American Society of Anesthesiologists (ASA) classifications, time-weighted area under the curve (TW-AUC) for mean blood pressure (MBP) <60 mmHg, total intraoperative fluid input and output, red blood cell (RBC) and plasma transfusion, duration of CPB, duration of aortic cross-clamping (ACC), and type of surgery. For laboratory parameters, when multiple measurements were available, the first result recorded within 24 hours of admission was used.

TyG-BMI Index Calculation and Outcome

TyG-BMI index was calculated as follows: TyG-BMI = ln[triglyceride (mg/dL) $\times$ fasting glucose (mg/dL)/2] $\times$ BMI (kg/m^2). The primary outcome was CSA-AKI. Based on the Kidney Disease: Improving Global Outcomes (KDIGO) guidelines, AKI was defined as meeting either of the following criteria: (1) an increase in Scr $\geq$0.3 mg/dL ($\geq$26.5 µmol/L) within 48 hours and (2) an increase in Scr to $\geq$1.5 times the baseline value within 7 days [21].

Statistical Analysis

Variables with more than 20% missing data were excluded from the analysis. For variables with less than 20%

missing data, multiple imputation using the random forest algorithm was applied (**Supplementary Table 1**). Categorical variables were expressed as counts (percentages) and analyzed using Pearson's χ^2 test. Non-normally distributed continuous variables, as assessed by the Shapiro-Wilk test, were expressed as median [interquartile range, IQR], and compared using the Kruskal-Wallis test or Mann-Whitney U test.

The discriminative performance of TyG-BMI, TyG index, and BMI for predicting CSA-AKI was assessed using receiver operating characteristic (ROC) analysis and the corresponding area under the curve (AUC). TyG-BMI, TyG, and BMI were sequentially incorporated into the baseline model to generate three predictive models, and their predictive performance was compared using AUC.

Internal validation was performed using non-parametric bootstrap resampling with 1000 iterations on the entire study cohort. For each iteration, a bootstrap sample was generated by sampling with replacement from the original dataset, the model was refitted to each sample, and its performance was assessed using Harrell's C-statistic. This approach provided bias-corrected estimates and enhanced the reliability of predictive performance measures for internal generalizability.

Furthermore, model performance was compared using net reclassification improvement (NRI) and integrated discrimination improvement (IDI). Multivariable logistic regression models were constructed to evaluate the association between TyG-BMI and CSA-AKI and to estimate odds ratios (ORs) with 95% confidence intervals (CIs), incorporating variables with $p < 0.05$ in univariate analyses (Table 1). Restricted cubic splines (RCS) were applied to assess the potential nonlinear association between TyG-BMI and CSA-AKI risk across the entire study cohort.

Moreover, participants were categorized based on cut-off values derived from ROC or RCS analysis, and subgroup analyses were performed to examine effect heterogeneity by age ($\leq$59 vs. $>$59 years), sex, hypertension, diabetes, and CHD. Multiple comparisons were adjusted using the Bonferroni correction, establishing a significance threshold at $p < 0.010$ (0.05/5). Subgroup-specific p-values were interpreted accordingly.

All statistical analyses were performed using R (version 4.2.2, R Foundation for Statistical Computing, Vienna, Austria) and the MSTATA platform (https://www.mstata.com/). A two-sided $p < 0.05$ was considered statistically significant.

Results

Patient Baseline Characteristics Categorized by CSA-AKI Status

The final study cohort comprised 652 patients (Fig. 1), of whom 224 (34.4%) developed CSA-AKI (Table 1). The median age was 59 years, and 52.1% of participants were female. A significant difference was observed in TyG-BMI distribution between the CSA-AKI (n = 224) and non-CSA-AKI (n = 428) groups. The CSA-AKI group exhibited a higher prevalence of preoperative hypertension, diabetes, CHD, and hyperuricemia, compared to the non-CSA-AKI group. The CSA-AKI group showed distinct laboratory features, including decreased eGFR, elevated BUN, and more frequent use of cardiovascular, antidiabetic, and lipid-lowering therapies. Intraoperatively, the CSA-AKI cohort experienced longer anesthesia duration, extended ACC times, greater exposure to TW-AUC MBP $<$60 mmHg, and lower total fluid input and output. No significant differences were recorded for other variables. Baseline characteristics across TyG-BMI quartiles are provided in **Supplementary Table 2**.

ROC Analysis of TyG-BMI

TyG-BMI demonstrated superior discriminatory performance for CSA-AKI than either TyG or BMI alone (AUC: 0.712 vs. 0.666 and 0.681, **Supplementary Table 3**). DeLong tests revealed that the AUC of TyG-BMI was significantly higher than BMI ($p < 0.001$) and TyG ($p = 0.021$). The optimal TyG-BMI cutoff was 195, yielding a sensitivity of 73.2% and a specificity of 62.9% (**Supplementary Table 3**).

To evaluate incremental predictive value, TyG-BMI, TyG, and BMI were incorporated into the baseline predictive model, as they are simple, clinically accessible preoperative metabolic and anthropometric markers. Despite notable differences in baseline characteristics between groups (Table 1), multivariable adjustments were applied to the baseline predictive model to account for these imbalances and assess the additional discriminatory power of each selected index.

Development of a CSA-AKI Predictive Model Using TyG-BMI, TyG, and BMI

Predictive models were developed for the entire cohort to assess the clinical utility of TyG-BMI, TyG, and BMI. The baseline predictive model had an AUC of 0.773, which was 0.740 in the internal validation set. Incorporating TyG-BMI into the basic model increased the AUC to 0.814, with a corresponding internal validation AUC of 0.785 (Table 2, **Supplementary Figs. 1–4**). Adding either TyG or BMI to the baseline model also improved discrimination, although the increase was less pronounced than with TyG-BMI. TyG-BMI provided statistically significant improvements in both the NRI and IDI compared to TyG and BMI, respectively. Compared with TyG, TyG-BMI improved net reclassification and integrated discrimination (NRI = 0.597 and IDI = 0.043; both $p < 0.001$). Comparison with the BMI, TyG-BMI yielded NRI = 0.597 ($p < 0.001$) and IDI = 0.012 ($p = 0.008$) (**Supplementary Table 4**).

Table 1. Patient demographics and baseline characteristics stratified by the CSA-AKI.

Characteristic	Overall, N = 652	No, N = 428	Yes, N = 224	Z-score/χ^2	*p*-value
TyG-BMI	195 [166, 220]	182 [161, 208]	211 [192, 235]	8.88	<0.001
Age (years)	59 [51, 65]	57 [49, 64]	61 [54, 66]	4.35	<0.001
Sex (female)	340 (52.1)	253 (59.1)	87 (38.8)	24.22	<0.001
BMI (kg/m^2)	22.5 [19.9, 24.8]	21.8 [19.5, 23.9]	23.7 [21.9, 26.2]	6.98	<0.001
Preoperative medical histories					
Hypertension	181 (27.8)	92 (21.5)	89 (39.7)	24.39	<0.001
Diabetes	96 (14.7)	43 (10.0)	53 (23.7)	21.71	<0.001
Coronary heart disease	340 (52.1)	204 (47.7)	136 (60.7)	10.04	0.002
Hyperuricemia	235 (36.0)	136 (31.8)	99 (44.2)	9.84	0.002
Preoperative laboratory results					
Albumin (g/L)	39.1 [36.7, 41.8]	39.4 [36.7, 42.0]	38.7 [36.7, 41.3]	–1.62	0.105
LDL-C (mg/dL)	94 [75, 117]	94 [75, 116]	96 [76, 119]	0.74	0.458
HDL-C (mg/dL)	46 [38, 55]	47 [38, 56]	44 [38, 52]	–1.71	0.087
eGFR (mL/min/1.73 m^2)	83 [69, 100]	86 [69, 101]	79 [66, 98]	–2.81	0.005
BUN (mmol/L)	5.87 [4.57, 7.78]	5.61 [4.47, 7.59]	6.41 [5.00, 7.99]	2.72	0.006
TyG index	8.55 [8.18, 9.02]	8.42 [8.07, 8.88]	8.74 [8.44, 9.22]	6.98	<0.001
TG (mg/dL)	105 [77, 153]	97 [73, 139]	127 [94, 175]	6.31	<0.001
Glucose (mg/dL)	92 [82, 115]	90 [80, 109]	97 [86, 132]	4.70	<0.001
Hemoglobin (g/L)	135 [123, 148]	134 [122, 148]	138 [124, 148]	0.95	0.341
Preoperative LVEF (%)	63 [58, 68]	64 [60, 68]	62 [56, 68]	–2.25	0.024
Coronary Angiography	503 (77.1)	320 (74.8)	183 (81.7)	4.01	0.045
Preoperative medications					
Cardiovascular medications	454 (69.6)	281 (65.7)	173 (77.2)	9.32	0.002
Lipid-lowering medications	265 (40.6)	148 (34.6)	117 (52.2)	18.99	<0.001
Anti-diabetic medications	77 (11.8)	38 (8.9)	39 (17.4)	10.28	0.001
Diuretic medications	611 (93.7)	398 (93.0)	213 (95.1)	1.10	0.294
Surgical information					
ASA classifications				2.07	0.150
II–III	204 (31.3)	142 (33.2)	62 (27.7)		
IV–V	448 (68.7)	286 (66.8)	162 (72.3)		
TW-AUC MBP <60 mmHg	1.77 [0.91, 2.95]	1.67 [0.87, 2.80]	2.02 [1.05, 3.53]	3.15	0.002
Total intraoperative output (mL)	1200 [1000, 1700]	1300 [1000, 1700]	1200 [900, 1600]	–2.68	0.007
Total intraoperative input (mL)	1000 [1000, 1000]	1000 [1000, 1250]	1000 [500, 1000]	–2.13	0.033
RBC transfusion	80 (12.3)	46 (10.7)	34 (15.2)	2.68	0.101
Plasma transfusion	311 (47.7)	188 (43.9)	123 (54.9)	7.11	0.008
The length of anesthesia (min)	355 [300, 420]	340 [295, 405]	385 [333, 458]	6.35	<0.001
The length of ACC (min)	104 [74, 143]	96 [69, 138]	120 [88, 154]	5.68	<0.001
Surgical types				19.42	<0.001
Great vessels	36 (5.5)	23 (5.4)	13 (5.8)		
Valves	468 (71.8)	291 (68.0)	177 (79.0)		
CABG and valves	25 (3.8)	15 (3.5)	10 (4.5)		
CABG	40 (6.1)	27 (6.3)	13 (5.8)		
Others	83 (12.7)	72 (16.8)	11 (4.9)		

Categorical data is expressed as n (percentage), and continuous data as median [quartiles]. CSA-AKI, cardiac surgery-associated acute kidney injury; TyG-BMI, triglyceride glucose-body mass index; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; eGFR, estimated Glomerular Filtration Rate; BUN, blood urea nitrogen; LVEF, left ventricular ejection fraction. ASA, American Society of Anesthesiologists; TW-AUC MBP <60 mmHg, the time-weighted area under the curve mean blood pressure <60 mmHg; RBC, red blood cell; ACC, aortic cross-clamping; CABG, coronary artery bypass grafting. Other surgery types included congenital heart disease surgery and cardiac myxoma surgery.

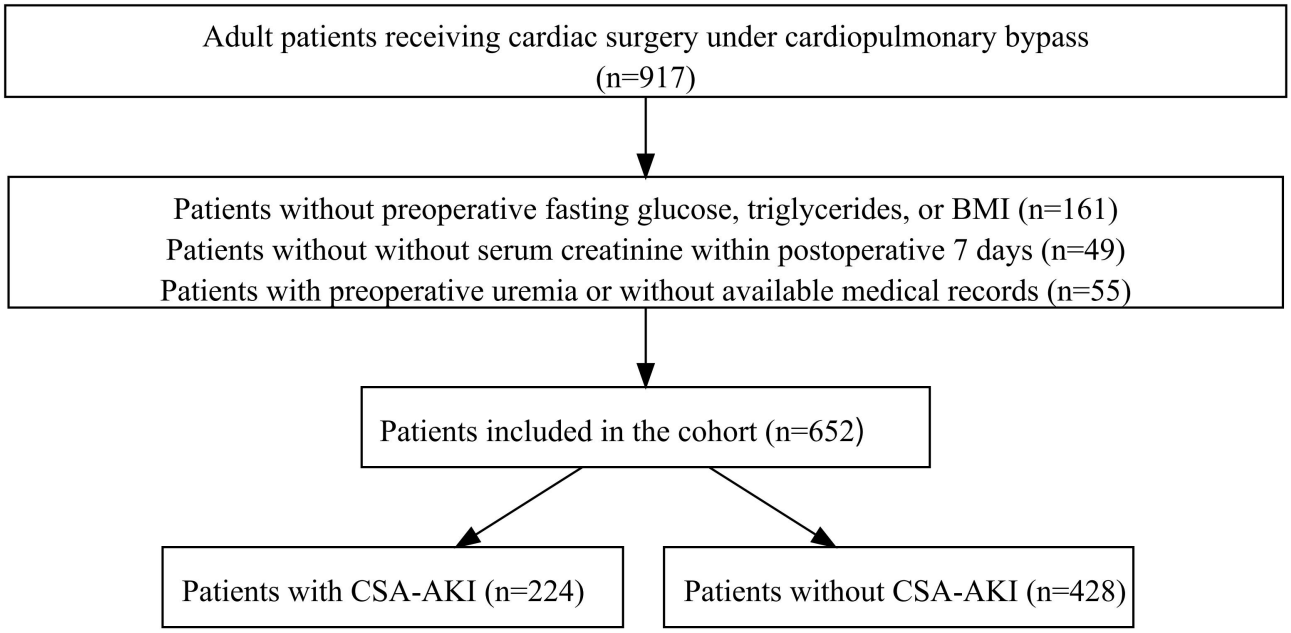

Fig. 1. A flowchart of patient selection. BMI, body mass index; CSA-AKI, cardiac surgery-associated acute kidney injury.

Table 2. Predictive performance of the basic model versus other indexes.

	AUC		Comparison			
	Overall cohort	Internal validation (bootstrap, 1000 times)	NRI (continuous)	*p*-value	IDI	*p*
Basic model	0.773 (0.735–0.810)	0.740	/		/	
+ TyG-BMI vs. Basic model	0.814 (0.780–0.848)	0.785	0.597 (0.523–0.669)	<0.001	0.069 (0.048–0.091)	<0.001
+ TyG vs. Basic model	0.794 (0.759–0.830)	0.777	0.557 (0.478–0.631)	<0.001	0.027 (0.012–0.040)	<0.001
+ BMI vs. Basic model	0.805 (0.770–0.840)	0.776	0.585 (0.511–0.655)	<0.001	0.058 (0.039–0.076)	<0.001

Abbreviations: AUC, area under the curve; NRI, net reclassification improvement; IDI, integrated discrimination improvement.
+ indicates addition of the variable to the basic model.

Logistic Regression and RCS of TyG-BMI and CSA-AKI

As detailed in Table 3, the association between TyG-BMI and CSA-AKI remained significant after adjusting for potential confounders. In Model 3, each 15-unit increase in TyG-BMI was linked to a 41% higher likelihood of CSA-AKI (adjusted OR 1.41, 95% CI 1.28–1.55; $p < 0.001$). Compared to Q1, the risk of CSA-AKI was significantly increased in Q3 and Q4 quartiles across all models (all $p < 0.001$), whereas Q2 did not differ significantly from Q1 (all $p > 0.05$). Multivariable-adjusted RCS modeling revealed a linear association between TyG-BMI and CSA-AKI risk (nonlinearity, $p = 0.496$; overall $p < 0.001$; Fig. 2), with a progressive increase in CSA-AKI odds as TyG-BMI increased.

Subgroup Analyses and CSA-AKI Risk

Subgroup analyses indicated that a TyG-BMI ≥195 was associated with an elevated risk of CSA-AKI (OR = 4.71, 95% CI = 3.13–7.09, $p < 0.001$, Fig. 3), with consistent outcomes across subgroups defined by age, sex, hypertension, and CHD. However, among patients without diabetes, a TyG-BMI ≥195 significantly increased the risk of CSA-AKI (OR = 4.87, 95% CI = 3.12–7.61, $p < 0.001$), whereas no substantial association was observed in those with diabetes (OR = 2.33, 95% CI = 0.50–10.79, $p = 0.279$). No significant interactions were found across the examined subgroups (Fig. 3).

Discussion

This retrospective study shows that the TyG-BMI index outperforms TyG or BMI alone in predicting CSA-AKI. Elevated preoperative TyG-BMI demonstrates an independent, dose-dependent association with CSA-AKI risk. Moreover, TyG-BMI serves as a novel stratification tool, independent of traditional risk factors. To date, limited studies have examined the relationship of preoperative IR and body fat abnormalities with CSA-AKI risk.

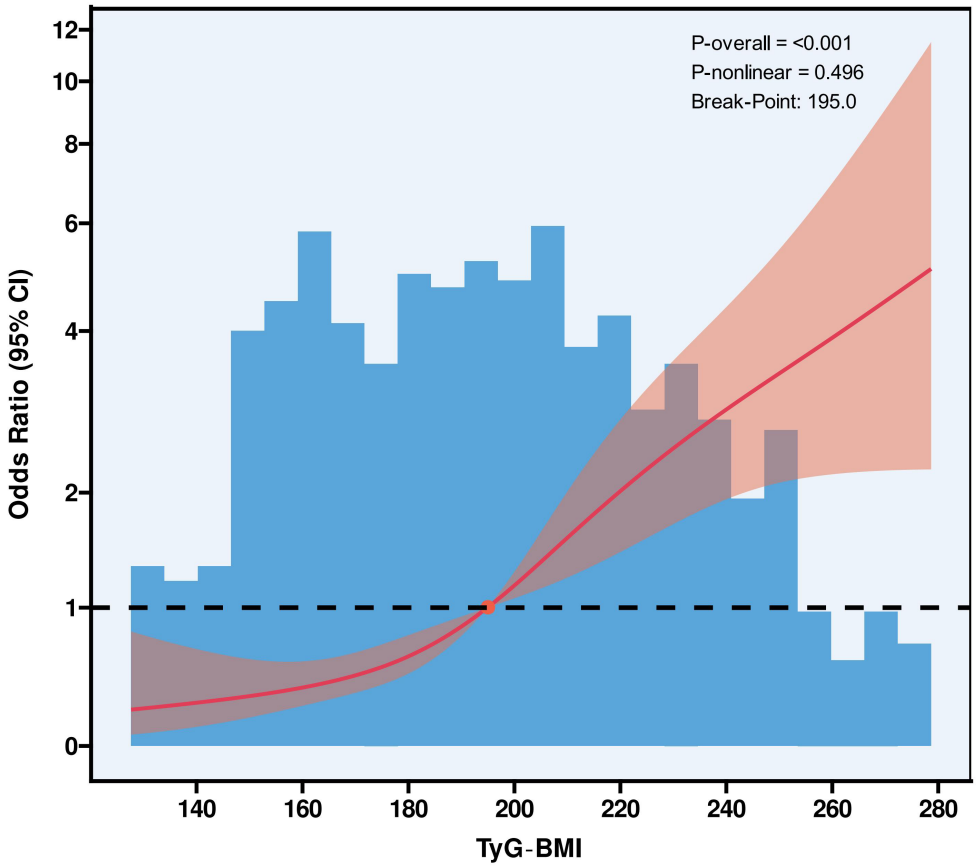

Fig. 2. Restricted cubic spline of the linear relationship between preoperative TyG-BMI and CSA-AKI risk. The x-axis represents TyG-BMI values (range: 140–280) and the y-axis shows the OR with 95% CI. The solid red line denotes the adjusted OR trend, and the pink-shaded area indicates the 95% CI. A solid red point marks a breakpoint at 195.0. Abbreviations: TyG-BMI, triglyceride-glucose-body mass index; CI, confidence interval.

Table 3. Logistic regression outcomes of the TyG-BMI and CSA-AKI.

Variables	Model 1 (crude)		Model 2 (adjusted)		Model 3 (adjusted)	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Continuous TyG-BMI per 15 units	1.39 (1.29–1.50)	<0.001	1.35 (1.24–1.48)	<0.001	1.41 (1.28–1.55)	<0.001
TyG-BMI quartiles [range]						
Q1 [106,165]	Reference		Reference		Reference	
Q2 [166,194]	1.39 (0.79–2.44)	0.254	1.06 (0.59–1.92)	0.846	0.88 (0.47–1.68)	0.707
Q3 [195,219]	4.49 (2.67–7.56)	<0.001	3.54 (2.04–6.16)	<0.001	3.70 (2.04–6.72)	<0.001
Q4 [220,403]	6.34 (3.77–10.66)	<0.001	4.48 (2.52–7.99)	<0.001	5.00 (2.68–9.35)	<0.001

OR, odds ratio; CI, confidence interval; Model 1: crude. Model 2: adjusted: age, gender, hypertension, diabetes, coronary heart disease, hyperuricemia, eGFR, blood urea nitrogen, cardiovascular medications, lipid-lowering medications, anti-diabetic medications, coronary angiography, left ventricular ejection fraction. Model 3: adjusted for variables in Model 2, and the length of anesthesia, time-weighted area under the curve, mean blood pressure <60 mmHg, total intraoperative output and input, plasma transfusion, the length of aortic cross-clamping, and surgical types.

TyG-BMI is an independent determinant of CKD risk [22]. Elevated TyG correlates with declining renal function in the general population [23] and can lead to endothelial dysfunction and renal interstitial fibrosis, thereby promoting the progression of CKD [24–26]. In critically ill patients with heart failure, higher TyG values reliably predict AKI and renal impairment [19]. In individuals undergoing coronary artery bypass grafting (CABG), preoperative TyG levels effectively predict postoperative renal complications, with a clear dose-response relationship across various subgroups [11].

BMI primarily reflects the ratio of body weight to height and is linked to altered renal hemodynamics and activated inflammatory responses [27]. BMI has been strongly

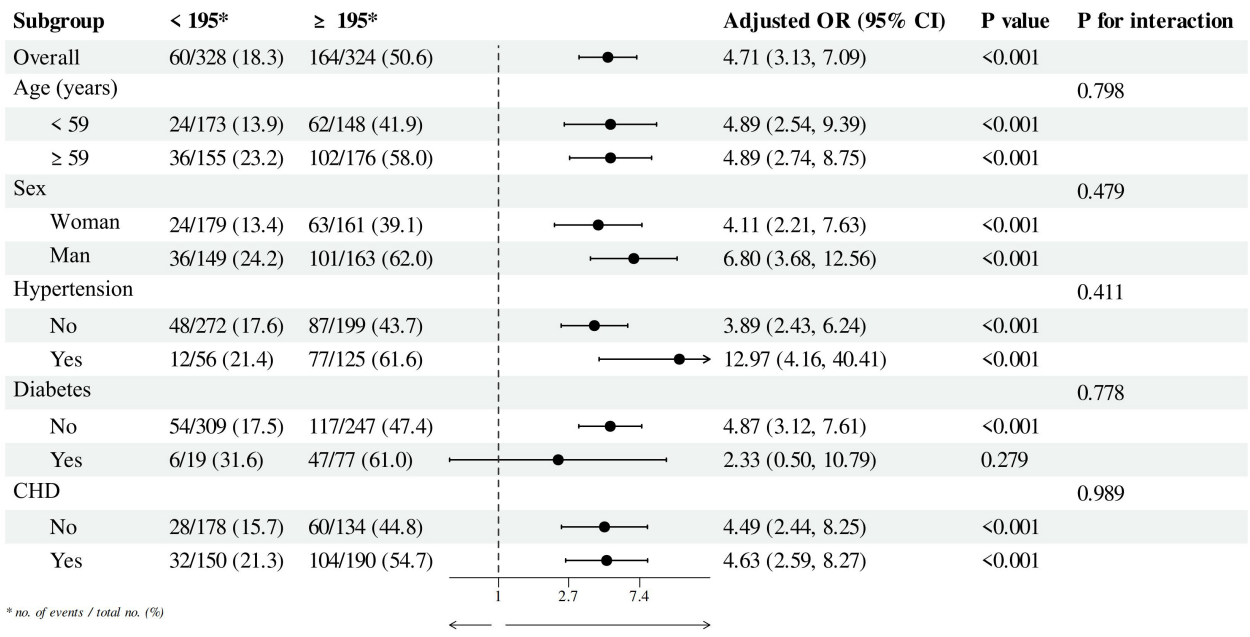

Fig. 3. Subgroup analysis of TyG-BMI threshold and CSA-AKI risk. This forest plot demonstrates the adjusted ORs and 95% CIs for the association between elevated TyG-BMI ≥195 and CSA-AKI across predefined subgroups. The reference line (OR) is at 1. Abbreviations: TyG-BMI, triglyceride-glucose-body mass index; CHD, coronary heart disease.

associated with an increased risk of CSA-AKI [12]. However, BMI alone can be a misleading marker in AKI risk assessment [17], as patients with high muscle mass may have an elevated BMI driven by lean tissue, leading to overestimation of AKI risk. Conversely, individuals with high body fat but normal BMI, such as those with "normal-weight metabolic obesity", may be overlooked despite underlying IR.

This study is the first to assess the combined effects of IR and obesity on CSA-AKI risk. The findings indicate that higher TyG-BMI values are independently and linearly associated with an increased risk of CSA-AKI, with a substantial increase in risk beyond the optimal cutoff of 195, suggesting a cumulative detrimental effect of concurrent metabolic impairment and obesity. Compared with TyG or BMI alone, TyG-BMI better reflects the combined impact of metabolic and adiposity-related pathways on renal injury and reduces misclassification that may occur when relying solely on BMI. These observations support the use of TyG-BMI as a more informative option for early risk assessment and preoperative guidance in patients undergoing cardiac surgery.

Although subgroup analyses generally yield consistent outcomes, these findings should be interpreted with caution, given the small sample sizes in certain strata. Particularly, TyG-BMI was not significantly linked to CSA-AKI risk among diabetic patients, indicating inadequate statistical power. Additionally, intensive glucose-lowering interventions in these patients may reduce variability in fasting glucose and triglyceride levels, thereby attenuating the predictive utility of TyG-BMI. The inherently elevated baseline TyG-BMI values in diabetics, along with heterogeneity in diabetes duration and microvascular complications, may further obscure potential associations. Despite this, the consistency observed across non-diabetic and other subgroups reinforces the overall performance of TyG-BMI and highlights the need for prospective validation in diabetic cohorts.

The association between TyG-BMI and CSA-AKI is likely mediated by inflammatory responses and renal structural and tubular damage caused by IR and adiposity-related abnormalities. Elevated TyG reflects hypertriglyceridemia and hyperglycemia, which exacerbate oxidative stress and systemic inflammation [28]. IR disrupts insulin signaling pathways, leading to injury of podocytes, tubular epithelial cells, mesangial cells, and endothelial cells [29–32]. Obesity further exacerbates renal injury through adipokine imbalance (e.g., altered leptin and adiponectin levels), promoting renal tubular epithelial apoptosis and interstitial fibrosis, while elevated BMI is linked to increased renal vascular resistance [33].

Additionally, obesity and metabolic dysfunction also activate the renin-angiotensin and sympathetic nervous systems [33], inducing glomerular hyperfiltration and tubular injury, thereby increasing CSA-AKI risk. In cardiac surgery, patients with increased preoperative TyG-BMI may already carry renal microvascular and cellular injury, along with abnormal filtration dynamics [13,34], which are further worsened by perioperative hemodynamic instability, systemic inflammation, and oxidative stress [35].

These mechanisms contribute to renal microvascular dysfunction and AKI. Additionally, suboptimal fluid management in obese patients and the use of vasopressors can further compromise renal perfusion, particularly during non-pulsatile CPB flow [36]. Blood-material contact and surgical interventions during CPB also predispose to ischemia-reperfusion injury, with stress conditions, amplifying inflammatory and oxidative responses. IR impairs vasodilation and promotes renal hypoperfusion, exacerbating renal ischemia-reperfusion injury and establishing a self-perpetuating injury cycle [37]. TyG-BMI is an integrated marker of metabolic and adiposity abnormalities and may therefore be useful for identifying patients at increased risk of postoperative renal complications. However, further mechanistic studies are needed to clarify how TyG-BMI-related cascades interact with CPB-associated mechanisms in the development of CSA-AKI.

Patients with elevated preoperative TyG-BMI are likely to have underlying renal impairment and increased inflammation. In our study, TyG-BMI demonstrated the highest improvement in both discrimination and integrated discrimination indices (NRI and IDI) for predicting CSA-AKI, confirming its significance as an effective biomarker for clinical risk stratification and early preventive interventions. Extending previous observations, which primarily focused on specific cohorts such as diabetic or CABG patients, this study assessed TyG-BMI in unselected cardiac surgery patients. Our study included participants from various surgical categories, including valve and great vessel procedures, addressing a significant evidence gap and showing the robustness of TyG-BMI across a broad clinical spectrum. These results support TyG-BMI as a robust biomarker of IR and adiposity with practical applicability in preoperative risk stratification. The consistent associations observed in this wider cohort provide a foundation for future studies in even more heterogeneous populations to optimize early management strategies aimed at alleviating CSA-AKI.

The importance of perioperative glucose optimization is well-established in cardiac surgical care. Obesity, a modifiable risk factor, can be managed through weight control to reduce postoperative CSA-AKI risk [4]. However, clear preoperative weight management strategies specific to cardiac surgery patients are still lacking. Similarly, the role of preoperative lipid management in reducing CSA-AKI risk remains unclear [38,39], and a recent RCT even suggested that preoperative rosuvastatin use may increase AKI risk [40]. These discrepancies may be due to differences in study design, including sample sizes, statin type and dose, timing of administration, and heterogeneity in patient populations and AKI diagnostic criteria.

Given that patients with increased TyG-BMI often present with cardiovascular disease or diabetes, future research should focus on defining optimal preoperative strategies for glucose, lipid, and weight management, alongside personalized optimization of comorbidities. In clinical settings, TyG-BMI can be readily integrated into routine preoperative evaluation using standard fasting triglyceride, glucose, and BMI measurements. Patients with elevated TyG-BMI can be identified as high risk for CSA-AKI and considered for a multidisciplinary assessment to fine-tune metabolic parameters. Early interventions include intensified perioperative glucose monitoring, tailored fluid and hemodynamic management during CPB, and carefully selected prophylactic medications. Integration of TyG-BMI into electronic health record systems as an automated risk alert may provide a cost-effective approach to support early prevention and personalized perioperative care.

Limitations

Despite its promising outcomes, this retrospective cohort study has certain limitations. First, the study was conducted in a single regional center, where perioperative management practices may differ from those in other medical centers, potentially influencing CSA-AKI incidence and limiting generalizability. Second, although adjustments were made for known confounders, residual confounding cannot be excluded, especially for unrecorded factors such as cumulative contrast doses and preoperative cystatin C levels. The retrospective design also limits definitive causal inferences regarding the relationships between TyG-BMI and CSA-AKI. Third, urine output data were unavailable due to inconsistent documentation in electronic medical records. Nonetheless, the use of Scr-based criteria aligns with established practices in many cardiac surgery AKI investigations, ensuring the validity of our creatinine-defined CSA-AKI outcomes. Future prospective studies should employ longitudinal designs to establish a causal association between preoperative TyG-BMI and CSA-AKI, assess temporal changes in TyG-BMI in relation to perioperative exposures, and further explore whether increased TyG-BMI directly contributes to CSA-AKI pathogenesis.

Conclusions

The preoperative TyG-BMI index can be an independent, linearly associated predictor of CSA-AKI and potentially enhance the accuracy of existing predictive models. Monitoring of TyG-BMI could facilitate early identification of high-risk patients and guide timely, targeted interventions to improve postoperative outcomes. These findings warrant further validation in future prospective studies.

Availability of Data and Materials

The corresponding author can provide access to the data used in this study upon request.

Author Contributions

PZ and YZ performed the study design, data collection and examination, data analysis, manuscript drafting, and critical revision. WW and JD performed the study design, data collection and examination, data analysis, and manuscript drafting. WL revised the study design and the study process, analyzed the results, contributed to manuscript drafting and critical revision. All authors have read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The research protocol was approved by the Ethics Committee of Meizhou People's Hospital (Approval No.: 2025-C-18). Due to the retrospective nature of the study and the anonymized handling of data, the ethics committee waived the requirement for individual informed consent. The study was registered with Chinese Clinical Trial Registry and adhered to the ethical standards outlined in the Declaration of Helsinki.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.24976/Discov.Med.202537203.246.

References

[1] Massoth C, Zarbock A, Meersch M. Acute Kidney Injury in Cardiac Surgery. Critical Care Clinics. 2021; 37: 267–278. https://doi.org/10.1016/j.ccc.2020.11.009.

[2] Vives M, Hernandez A, Parramon F, Estanyol N, Pardina B, Muñoz A, *et al*. Acute kidney injury after cardiac surgery: prevalence, impact and management challenges. International Journal of Nephrology and Renovascular Disease. 2019; 12: 153–166. https://doi.org/10.2147/IJNRD.S167477.

[3] Scurt FG, Bose K, Mertens PR, Chatzikyrkou C, Herzog C. Cardiac Surgery-Associated Acute Kidney Injury. Kidney360. 2024; 5: 909–926. https://doi.org/10.34067/KID.0000000000000466.

[4] Tinica G, Brinza C, Covic A, Popa IV, Tarus A, Bacusca AE, *et al*. Determinants of acute kidney injury after cardiac surgery: a systematic review. Reviews in Cardiovascular Medicine. 2020; 21: 601–610. https://doi.org/10.31083/j.rcm.2020.04.206.

[5] See CY, Pan HC, Chen JY, Wu CY, Liao HW, Huang YT, *et al*. Improvement of composite kidney outcomes by AKI care bundles: a systematic review and meta-analysis. Critical Care (London, England). 2023; 27: 390. https://doi.org/10.1186/s13054-023-04641-0.

[6] Lindhardt RB, Rasmussen SB, Riber LP, Lassen JF, Ravn HB. The Impact of Acute Kidney Injury on Chronic Kidney Disease After Cardiac Surgery: A Systematic Review and Meta-analysis. Journal of Cardiothoracic and Vascular Anesthesia. 2024; 38: 1760–1768. https://doi.org/10.1053/j.jvca.2024.03.044.

[7] Leballo G, Chakane PM. Cardiac surgery-associated acute kidney injury: pathophysiology and diagnostic modalities and management. Cardiovascular Journal of Africa. 2020; 31: 205–212. https://doi.org/10.5830/CVJA-2019-069.

[8] Yu Y, Li C, Zhu S, Jin L, Hu Y, Ling X, *et al*. Diagnosis, pathophysiology and preventive strategies for cardiac surgery-associated acute kidney injury: a narrative review. European Journal of Medical Research. 2023; 28: 45. https://doi.org/10.1186/s40001-023-00990-2.

[9] Callejas R, Panadero A, Vives M, Duque P, Echarri G, Monedero P, *et al*. Preoperative predictive model for acute kidney injury after elective cardiac surgery: a prospective multicenter cohort study. Minerva Anestesiologica. 2019; 85: 34–44. https://doi.org/10.23736/S0375-9393.18.12257-7.

[10] Lin X, Xiao L, Lin W, Wang D, Xu K, Kuang L. A model for predicting AKI after cardiopulmonary bypass surgery in Chinese patients with normal preoperative renal function. BMC Surgery. 2024; 24: 383. https://doi.org/10.1186/s12893-024-02683-x.

[11] Hou B, Hou X, Liu D, Liu T, Zhang K, Li Y, *et al*. Predictive value of the triglyceride-glucose index for coronary artery bypass grafting-acute kidney injury patients. BMC Cardiovascular Disorders. 2025; 25: 206. https://doi.org/10.1186/s12872-025-04584-0.

[12] Shi N, Liu K, Fan Y, Yang L, Zhang S, Li X, *et al*. The Association Between Obesity and Risk of Acute Kidney Injury After Cardiac Surgery. Frontiers in Endocrinology. 2020; 11: 534294. https://doi.org/10.3389/fendo.2020.534294.

[13] Zhao S, Yu S, Chi C, Fan X, Tang J, Ji H, *et al*. Association between macro- and microvascular damage and the triglyceride glucose index in community-dwelling elderly individuals: the Northern Shanghai Study. Cardiovascular Diabetology. 2019; 18: 95. https://doi.org/10.1186/s12933-019-0898-x.

[14] Shi Y, Duan H, Liu J, Shi X, Zhao M, Zhang Y. Association of triglyceride glucose index with the risk of acute kidney injury in patients with coronary revascularization: a cohort study. Diabetology & Metabolic Syndrome. 2024; 16: 117. https://doi.org/10.1186/s13098-024-01358-0.

[15] Argalious MY, Makarova N, Leone A, Cywinski J, Farag E. Association of Body Mass Index and Postoperative Acute Kidney Injury in Patients Undergoing Laparoscopic Surgery. Ochsner Journal. 2017; 17: 224–232.

[16] Kim B, Kim GM, Han K, Maki N, Taniguchi K, Oh S. The Triglyceride-Glucose Index is Independently Associated with Chronic Kidney Disease in the Geriatric Population, Regardless of Obesity and Sex. Annals of Geriatric Medicine and Research. 2023; 27: 258–265. https://doi.org/10.4235/agmr.23.0096.

[17] Bai YX, Wang ZH, Lv Y, Liu J, Xu ZZ, Feng YQ, *et al*. Association between frailty and acute kidney injury after cardiac surgery: unraveling the moderation effect of body fat through an international, retrospective, multicohort study. International Journal of Surgery (London, England). 2025; 111: 761–770. https://doi.org/10.1097/JS9.0000000000001861.

[18] Er LK, Wu S, Chou HH, Hsu LA, Teng MS, Sun YC, *et al*. Triglyceride Glucose-Body Mass Index Is a Simple and Clinically Useful Surrogate Marker for Insulin Resistance in Nondi-

abetic Individuals. PloS One. 2016; 11: e0149731. https://doi.org/10.1371/journal.pone.0149731.

[19] Yang Z, Gong H, Kan F, Ji N. Association between the triglyceride glucose (TyG) index and the risk of acute kidney injury in critically ill patients with heart failure: analysis of the MIMIC-IV database. Cardiovascular Diabetology. 2023; 22: 232. https://doi.org/10.1186/s12933-023-01971-9.

[20] Lan J, Xu G, Zhu Y, Lin C, Yan Z, Shao S. Association of Body Mass Index and Acute Kidney Injury Incidence and Outcome: A Systematic Review and Meta-Analysis. Journal of Renal Nutrition: the Official Journal of the Council on Renal Nutrition of the National Kidney Foundation. 2023; 33: 397–404. https://doi.org/10.1053/j.jrn.2023.01.005.

[21] Khwaja A. KDIGO clinical practice guidelines for acute kidney injury. Nephron. Clinical Practice. 2012; 120: c179–c184. https://doi.org/10.1159/000339789.

[22] Fan C, Guo M, Chang S, Wang Z, An T. Elevated TyG-BMI index predicts incidence of chronic kidney disease. Clinical and Experimental Medicine. 2024; 24: 203. https://doi.org/10.1007/s10238-024-01472-3.

[23] Yoshida D, Ikeda S, Shinohara K, Kazurayama M, Tanaka S, Yamaizumi M, *et al*. Triglyceride-Glucose Index Associated with Future Renal Function Decline in the General Population. Journal of General Internal Medicine. 2024; 39: 3225–3233. https://doi.org/10.1007/s11606-024-08809-4.

[24] Zhang W, Yang Z. Association between the triglyceride glucose index and the risk of acute kidney injury in critically ill patients with hypertension: analysis of the MIMIC-IV database. Frontiers in Endocrinology. 2024; 15: 1437709. https://doi.org/10.3389/fendo.2024.1437709.

[25] Yu P, Pu J, Yuan Q, Huang L, Tao L, Peng Z. The prognostic value of triglyceride-glucose index to adverse renal outcomes in patients with type 2 diabetes mellitus: results from the cohort study of ACCORD. Diabetology & Metabolic Syndrome. 2024; 16: 201. https://doi.org/10.1186/s13098-024-01439-0.

[26] Kinguchi S, Tamura K. Triglyceride-glucose index is a good indicator for early prediction of future chronic kidney disease development in all blood pressure subtypes. Hypertension Research: Official Journal of the Japanese Society of Hypertension. 2024; 47: 805–807. https://doi.org/10.1038/s41440-023-01577-4.

[27] Madani S, Masoumi SJ, Ahmadi A, Zare M, Hejazi N, Foshati S. The relationship between kidney function and cardiometabolic risk factors, anthropometric indices, and dietary inflammatory index in the Iranian general population: a cross-sectional study. BMC Nephrology. 2025; 26: 5. https://doi.org/10.1186/s12882-024-03930-2.

[28] Zhou H, Ding X, Lan Y, Chen S, Wu S, Wu D. Multi-trajectories of triglyceride-glucose index and lifestyle with Cardiovascular Disease: a cohort study. Cardiovascular Diabetology. 2023; 22: 341. https://doi.org/10.1186/s12933-023-02076-z.

[29] Garner KL, Betin VMS, Pinto V, Graham M, Abgueguen E, Barnes M, *et al*. Enhanced insulin receptor, but not PI3K, signalling protects podocytes from ER stress. Scientific Reports. 2018; 8: 3902. https://doi.org/10.1038/s41598-018-22233-9.

[30] Carlsson AC, Calamia M, Risérus U, Larsson A, Helmersson-Karlqvist J, Lind L, *et al*. Kidney injury molecule (KIM)-1 is associated with insulin resistance: results from two community-based studies of elderly individuals. Diabetes Research and Clinical Practice. 2014; 103: 516–521. https://doi.org/10.1016/j.diabres.2013.12.008.

[31] Subathra M, Korrapati M, Howell LA, Arthur JM, Shayman JA, Schnellmann RG, *et al*. Kidney glycosphingolipids are elevated early in diabetic nephropathy and mediate hypertrophy of mesangial cells. American Journal of Physiology. Renal Physiology. 2015; 309: F204–F215. https://doi.org/10.1152/ajprenal.00150.2015.

[32] Sarafidis PA, Lasaridis AN. Insulin resistance and endothelin: another pathway for renal injury in patients with the cardiometabolic syndrome? Journal of the Cardiometabolic Syndrome. 2008; 3: 183–187. https://doi.org/10.1111/j.1559-4572.2008.00009.x.

[33] Yau K, Kuah R, Cherney DZI, Lam TKT. Obesity and the kidney: mechanistic links and therapeutic advances. Nature Reviews. Endocrinology. 2024; 20: 321–335. https://doi.org/10.1038/s41574-024-00951-7.

[34] Oh D, Park SH, Lee S, Yang E, Choi HY, Park HC, *et al*. High Triglyceride-Glucose Index with Renal Hyperfiltration and Albuminuria in Young Adults: The Korea National Health and Nutrition Examination Survey (KNHANES V, VI, and VIII). Journal of Clinical Medicine. 2022; 11: 6419. https://doi.org/10.3390/jcm11216419.

[35] Polyak P, Kwak J, Kertai MD, Anton JM, Assaad S, Dacosta ME, *et al*. Vasoplegic Syndrome in Cardiac Surgery: A Narrative Review of Etiologic Mechanisms and Therapeutic Options. Journal of Cardiothoracic and Vascular Anesthesia. 2025; 39: 1815–1829. https://doi.org/10.1053/j.jvca.2025.02.047.

[36] Suneja M, Kumar AB. Obesity and perioperative acute kidney injury: a focused review. Journal of Critical Care. 2014; 29: 694.e1–6. https://doi.org/10.1016/j.jcrc.2014.02.021.

[37] Zhang M, Liu Q, Meng H, Duan H, Liu X, Wu J, *et al*. Ischemia-reperfusion injury: molecular mechanisms and therapeutic targets. Signal Transduction and Targeted Therapy. 2024; 9: 12. https://doi.org/10.1038/s41392-023-01688-x.

[38] Xiong B, Nie D, Cao Y, Zou Y, Yao Y, Qian J, *et al*. Preoperative Statin Treatment for the Prevention of Acute Kidney Injury in Patients Undergoing Cardiac Surgery: A Meta-Analysis of Randomised Controlled Trials. Heart, Lung & Circulation. 2017; 26: 1200–1207. https://doi.org/10.1016/j.hlc.2016.11.024.

[39] Wang Y, Zhu S, DU R, Zhou J, Chen Y, Zhang Q. Statin initiation and renal outcomes following isolated coronary artery bypass grafting: a meta-analysis. The Journal of Cardiovascular Surgery. 2018; 59: 282–290. https://doi.org/10.23736/S0021-9509.17.10074-1.

[40] Zheng Z, Jayaram R, Jiang L, Emberson J, Zhao Y, Li Q, *et al*. Perioperative Rosuvastatin in Cardiac Surgery. The New England Journal of Medicine. 2016; 374: 1744–1753. https://doi.org/10.1056/NEJMoa1507750.