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Title

Association between the preoperative triglyceride-glucose index and myocardial injury following noncardiac surgery: a retrospective study

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Abstract

Objective: An elevated triglyceride-glucose (TyG) index positively correlates with adverse cardiovascular events. However, its association with myocardial injury after noncardiac surgery (MINS) remains unclear. This study aimed to examine the association between the preoperative TyG index and MINS.

Design: a retrospective study

Setting: The cohort of adult patients were extracted from the electronic medical system of Meizhou People's Hospital.

Participants: Adult patients under general anaesthesia and with MINS.

Main exposure measure: The preoperative TyG index, calculated using triglyceride (TG) and fasting blood glucose (FBG) levels.

Main outcome measure: The occurrence of MINS, defined using postoperative troponin measurements.

Results: The final cohort included 889 patients, with an 8.3% incidence of MINS (74/889). The median TyG index was 8.57 [8.13, 9.02]. TyG exhibited higher discriminatory ability for MINS than TG and FBG, with an area under the curve (AUC) of 0.624, 0.544, and 0.500, respectively.

Fully adjusted logistic regression indicated that an elevated TyG index was independently associated with MINS (odds ratio 1.75, 95% confidence interval 1.21–2.52; P = 0.003). A multivariate restricted cubic spline suggested a linear relationship between TyG and MINS (P for nonlinearity = 0.059). Subgroup analyses showed results consistent with the primary analysis, with no significant interaction effects between subgroups.

Conclusion: An elevated preoperative TyG index is independently associated with an increased incidence of MINS. Monitoring the TyG index perioperatively may improve the management of patients at risk for MINS.

Keywords: triglyceride, blood glucose, troponin, noncardiac surgery, general anaesthesia

Strengths and limitations of this study

1. Few studies have examined the association between the preoperative TyG index and MINS.

2. This study found that MINS independently correlates with the preoperative TyG index.

3. Postoperative troponin levels, rather than subjective symptoms, were used to diagnose MINS.

4. The study comprehensively evaluates the diagnostic performance and relationship between TyG and MINS.

5. As a retrospective study, it cannot establish a causal relationship between preoperative TyG and MINS.

Introduction

Myocardial injury after noncardiac surgery (MINS) occurs in approximately 3% to 16% of surgical cases, (1-3) and is a significant cause of mortality within 30 days postoperatively. (1, 4) The pathophysiology of MINS includes the disruption of atherosclerotic coronary plaques and an imbalance between myocardial oxygen supply and demand. Preoperative coronary angiography is not mandatory for individuals with coronary artery disease (CAD) who do not exhibit apparent myocardial ischemic symptoms, making it challenging to identify high-risk patients preoperatively. Therefore, clinicians need a convenient and practical index for this purpose. Significant risk factors

for CAD include dyslipidaemia and hyperglycaemia. Both obesity (5) and hyperglycaemia (6) have been strongly associated with subclinical myocardial injury (SCeMI), and adverse cardiovascular events (ACEs).

The triglyceride-glucose (TyG) index, derived from triglycerides (TG) and fasting blood glucose (FBG), has been linked to the severity of CAD and ACEs. (7-10) Elevated TyG index levels are associated with increased severity of coronary artery stenosis and a higher number of diseased vessels in patients with acute coronary syndrome. (11, 12) The TyG index is a robust predictor of subclinical CAD, even without traditional cardiovascular risk factors (CVRFs). (13) Furthermore, Kim et al. demonstrated a correlation between higher TyG index levels and the presence of coronary artery calcification plaques in healthy adults. (14) This observation suggests that patients indicated for operation who have a high TyG index and undergo general anaesthesia may possess underlying coronary artery atherosclerosis and a heightened risk of MINS, regardless of CVRFs. Since dyslipidaemia and hyperglycaemia are routinely detectable and modifiable preoperatively, understanding the relationship between MINS and the TyG index is crucial for perioperative management. However, there is limited research on this issue. Therefore, the clinical records from Meizhou People's Hospital were reviewed to investigate whether preoperative TyG levels were associated with MINS. Elevated preoperative TyG index was hypothesised as an independent risk factor for developing MINS.

Methods and materials

Ethics

The Ethical Review Board of Meizhou People's Hospital approved this retrospective cohort study, and informed consent was waived (Ethic No. 2023-C-92). This study is registered with the Chinese Clinical Trial Registry (No. ChiCTR2400082834).

Data Source

This retrospective study utilised medical records from Meizhou People's Hospital, including the Electronic Medical Record System, Surgical Anaesthesia System, Prescription System, and Laboratory and Examination Systems. The Department of Medical Data and the Department of Medical Administration granted access to these records. Weiming Chen and Fei Liang were responsible for data extraction and cleaning, adhering to the study protocol.

Study Population

Inclusion Criteria: Patients indicated for operation aged ≥40 years, who were administered general anaesthesia and those with troponin measurements recorded within three postoperative days. Exclusion Criteria: (1) Patients <40 years; (2) Patients admitted without FBG and TG measurements; (3) Patients lacking prescription information.

Exposure of interest

The primary exposure was the preoperative TyG index., calculated using the formula: TyG = ln (TG [mg/dL] × FBG [mg/dL] /2). (15, 16) The conversion formulas used were FBG (mg/dL) = FBG (mmol/L) × 18.0 and TG (mg/dL) = TG (mmol/L) × 88.6. If FBG and TG were measured multiple times preoperatively, the closest measurements to the operation time were utilised.

Variables

The potential variables were categorised into four groups: (1) demographic characteristics, including age, gender, and body mass index (BMI); (2) preoperative comorbidities, including congestive heart failure (CHF), hypertension, CAD, chronic obstructive pulmonary disease (COPD), diabetes, history of stroke, and peripheral vascular disease (PVD); (3) preoperative laboratory results, including haemoglobin (Hb) and estimated glomerular filtration rate (eGFR); (4) surgical information, including the American Society of Anesthesiologists (ASA) Physical Status Classification System, highest intraoperative heart rate to mean arterial pressure (HMR), duration of anaesthesia, and surgical categories.

Outcomes

The outcome of interest was MINS, defined by postoperative troponin levels exceeding the 99th percentile upper reference limit without nonischaemic causes. (17, 18)

Statistical Analysis

This retrospective study included as many individuals as possible; therefore, no power calculation was conducted. The random forest algorithm was used for multiple imputations of variables with <20% missing data. Variables with >20% missing data were excluded to avoid bias. Patients were categorised into four groups based on the TyG index quartiles. Categorical variables were expressed as proportions. Chi-square tests, Fisher's exact test, were used for unordered categorical variables, and Kruskal-Wallis tests for ordered categorical variables. Continuous variables, expressed as median (interquartile range [IQR]) due to non-normal distribution (per Shapiro–Wilk test), were analysed using the Mann–Whitney U test or Kruskal–Wallis rank sum

tests. The diagnostic performance of TyG for MINS was assessed using receiver operating characteristic (ROC) curves to determine the best cutoff value. Logistic regression analysis identified factors influencing MINS across three models: Model 1: Unadjusted; Model 2: Adjusted for variables with a P-value <0.2 in the univariate analysis, along with clinically relevant variables; Model 3: Adjusted for all predefined variables. Odds ratio (OR) and 95% confidence intervals (CI) were calculated for TyG and the outcome. The linear trend (P trend) was assessed, and a multivariate restricted cubic spline (RCS) model analysed the nonlinear relationship between baseline TyG and MINS. Post-hoc subgroup analyses were stratified by age (≤69 years and >69 years), gender, BMI (<25 and ≥25 kg/m^2), hypertension, and surgical category, with interaction effects tested between subgroups.

A P-value <0.05 indicated statistical significance in two-tailed tests. Based on the open-source R, all statistical analyses were conducted using Stata software (https://www.mstata.com/).

Patient and public involvement

This study did not involve members of the public or patients.

Results

Reporting guideline

This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. (19)

Cohort characteristics

A total of 889 patients undergoing general anaesthesia were included in the study (Figure 1). Patients were categorised into four groups based on their TyG index (Table 1). The TyG ranges for each group are specified in Table 1. More than half of the patients were men, with a median age of 64 years. The overall median TyG index for all patients was 8.57, and the incidence of MINS was 8.3%. The fourth quartile (Q4) group generally exhibited a higher BMI and a higher prevalence of preoperative hypertension, diabetes, and history of stroke. Patients with a lower TyG index exhibited a lower incidence of MINS than those with a higher TyG index (P = 0.009).

Table 1 Baseline characteristics for patients stratified by TyG index quartiles.

	Overall, N = 889	Q1, N = 223	Q2, N = 222	Q3, N = 222	Q4, N = 222	P
TyG index range	5.03 - 11.33	5.03 - 8.13	8.14 - 8.57	8.58 - 9.02	9.03 - 11.33	/
TyG index quartile	8.57 [8.13, 9.02]	7.85 [7.71, 8.03]	8.37 [8.25, 8.47]	8.75 [8.65, 8.89]	9.44 [9.21, 9.75]	<0.001
Age (years)	64 [55, 72]	64 [55, 73]	64 [55, 72]	65 [58, 73]	60 [54, 69]	<0.001

Sex, man	533 (60.0)	137 (61.4)	148 (66.7)	115 (51.8)	133 (59.9)	0.015
BMI (kg/m²)	22.1 [20.0, 24.6]	20.4 [18.7, 22.5]	21.9 [19.7, 24.0]	22.8 [20.8, 25.1]	23.5 [21.3, 25.5]	<0.001
Preoperative Lab results						
Hemoglobin (g/L)	129 [112, 140]	124 [109, 137]	128 [112, 138]	130 [116, 140]	131 [114, 145]	0.010
eGFR (mL/min/1.73 m²)	80 [68, 92]	81 [70, 93]	80 [70, 91]	78 [65, 91]	81 [68, 96]	0.220
Preoperative medical history						
CHF	19 (2.1)	4 (1.8)	4 (1.8)	7 (3.2)	4 (1.8)	0.753
Hypertension	199 (22.4)	27 (12.1)	40 (18.0)	60 (27.0)	72 (32.4)	<0.001
CAD	43 (4.8)	9 (4.0)	7 (3.2)	17 (7.7)	10 (4.5)	0.135
COPD	71 (8.0)	23 (10.3)	21 (9.5)	17 (7.7)	10 (4.5)	0.112
Diabetes	88 (9.9)	4 (1.8)	12 (5.4)	22 (9.9)	50 (22.5)	<0.001
Stroke	50 (5.6)	4 (1.8)	12 (5.4)	11 (5.0)	23 (10.4)	0.001
PVD	58 (6.5)	11 (4.9)	13 (5.9)	18 (8.1)	16 (7.2)	0.538
Preoperative medications						
Rate-controlling	38 (4.3)	9 (4.0)	8 (3.6)	14 (6.3)	7 (3.2)	0.362
Aspirin	26 (2.9)	6 (2.7)	6 (2.7)	7 (3.2)	7 (3.2)	0.983
Statins	81 (9.1)	16 (7.2)	18 (8.1)	25 (11.3)	22 (9.9)	0.442
ASA classification						0.888
I-II	57 (6.4)	12 (5.4)	17 (7.7)	13 (5.9)	15 (6.8)	
III	555 (62.4)	141 (63.2)	139 (62.6)	143 (64.4)	132 (59.5)	
IV-V	277 (31.2)	70 (31.4)	66 (29.7)	66 (29.7)	75 (33.8)	
Duration of anesthesia (mins)	200 [135, 260]	205 [140, 266]	200 [135, 274]	205 [140, 259]	184 [135, 245]	0.134
The highest intraoperative	1.32 [1.13, 1.62]	1.30 [1.10, 1.54]	1.32 [1.11, 1.64]	1.33 [1.16, 1.65]	1.33 [1.15, 1.65]	0.248
HMR						
Surgical procedures						0.002
Low-risk	47 (5.3)	12 (5.4)	13 (5.9)	3 (1.4)	19 (8.6)	
Thoracic	201 (22.6)	60 (26.9)	55 (24.8)	53 (23.9)	33 (14.9)	
Non-thoracic major	641 (72.1)	151 (67.7)	154 (69.4)	166 (74.8)	170 (76.6)	
Intraoperative bleeding (ml)	50 [20, 100]	50 [20, 100]	50 [20, 100]	50 [20, 100]	50 [15, 100]	0.405
Outcomes						
MINS within postoperative 3 days	74 (8.3)	10 (4.5)	15 (6.8)	20 (9.0)	29 (13.1)	0.009
Other variables						
TG (mmol/L)	1.19 [0.82, 1.68]	0.70 [0.59, 0.82]	1.04 [0.90, 1.22]	1.46 [1.20, 1.70]	2.16 [1.65, 3.07]	<0.001
Glucose (mmol/L)	5.38 [4.65, 6.83]	4.63 [4.15, 5.30]	5.13 [4.60, 6.04]	5.52 [4.96, 6.63]	7.22 [5.73, 10.25]	<0.001

Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; .BMI: Body Mass Index; eGFR: estimated Glomerular Filtration Rate (CKD-EPI formula); CHF: Congestive Heart Failure; CAD: Coronary Arterial Disease; COPD: Chronic Obstructive Pulmonary Disease; PVD: Peripheral Vascular Disease; ASA: American Society of Anesthesiologist. HMR: heart rate to mean arterial pressure.

Baseline Characteristics of Patients with and without MINS

Supplementary Table S1 details the differences between the MINS and non-MINS groups. The median TyG index was significantly higher in the MINS group than in the non-MINS group (P<0.001). The two groups significantly differed in preoperative eGFR (P = 0.002). Moreover, the

MINS group exhibited a significantly higher occurrence of COPD, a history of stroke, and PVD. Preoperative statin use was significantly lower in the non-MINS group (P = 0.027).

ROC Analysis

The TyG index demonstrated higher discriminatory accuracy for MINS than TG and FBG, with an area under the curve (AUC) of 0.624, 0.544, and 0.500, respectively (Supplementary Figure S1). The optimal cutoff value for the TyG index was identified as 8.73 (63.2% specificity and 60.8% sensitivity).

Multivariable Logistic Regression

The continuous TyG index was positively associated with MINS in the crude and adjusted models (Table 2). Neither the Q2 nor the Q3 group exhibited a significantly different risk of MINS than the Q1 group. However, the Q4 group exhibited a substantially increased risk of MINS across all models. A significant linear (P) trend was observed across models 1, 2, and 3.

Table 2 Univariate and multivariate logistic regression for TyG index and MINS

	Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Continuous TyG index per unit	1.72 (1.27 - 2.35)	<0.001	1.54 (1.11 - 2.15)	0.010	1.75 (1.21 - 2.52)	0.003
TyG index quartile group (range)						
Q1(5.03-8.13)	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2 (8.14-8.57)	1.54 (0.68 - 3.51)	0.301	1.27 (0.55 - 2.98)	0.575	1.44 (0.61 - 3.42)	0.404
Q3(8.58-9.02)	2.11 (0.96 - 4.61)	0.062	1.90 (0.85 - 4.27)	0.118	2.21 (0.95 - 5.17)	0.066
Q4(9.03–11.33)	3.20 (1.52 - 6.74)	0.002	2.63 (1.20 - 5.78)	0.016	3.37 (1.46 - 7.81)	0.005
P_{trend}	<0.001		0.006		0.002	

Model 1: Crude; Model 2: Adjusted for age, gender, COPD, PVD, CAD, history of stroke, rate-controlling medications, statins, and eGFR. Model 3: Adjust for age, gender, BMI, preoperative hemoglobin, eGFR, CHF, hypertension, CAD, COPD, diabetes, history of stroke, PVD, rate-controlling medications, aspirin, statins, ASA classification, duration of anesthesia, the highest intraoperative HMR, surgical procedures, intraoperative bleeding. Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; OR: Odds Ratio; CI: Confidence Interval; BMI: body mass index; eGFR: estimated glomerular filtration rate; CHF: congestive heart failure; CAD: coronary arterial disease; COPD: chronic obstructive pulmonary disease; PVD: peripheral vascular disease; ASA: American Society of Anesthesiologist; HMR: heart rate to mean arterial pressure.

RCS Analysis

The RCS analysis revealed a linear increase in the risk of MINS with rising TyG index values (P for nonlinear = 0.059) (Figure 2). The reference point was set at 8.58, consistent with the optimal cutoff value of 8.73 derived from the ROC analysis.

Subgroup analysis

For clinical application, patients were categorised into two groups based on the TyG index (≤8.73 vs. >8.73) to examine subgroup heterogeneity (Figure 3). A TyG index >8.73 was particularly prominent in the following subgroups: patients ≤69 years, female patients, patients with a BMI <25 kg/m², patients without hypertension, and patients undergoing non-thoracic surgery. There was no considerable interaction effect among these subgroups.

Discussion

This study reveals that an elevated preoperative TyG index is independently associated with MINS. Our research provides a novel perspective for risk stratification and management strategies related to MINS. Previous research on the relationship between the preoperative TyG index and postoperative ACEs has been limited.

An elevated TyG index can indicate an increased risk for ACEs. (14, 20, 21) However, the relationship between the preoperative TyG index and MINS remains ambiguous. According to Liu et al., the TyG index is a significant biomarker of SCeMI. (22) Similarly, our study demonstrates a correlation between an elevated preoperative TyG index and a greater risk of MINS, complementing these findings. Compared to FBG and TG, the TyG index demonstrates more robust diagnostic efficacy for MINS, possibly because it more comprehensively reflects the body's metabolic status and arterial disease state. The linear association between the preoperative TyG index and MINS suggests that the TyG index could be used to predict the incidence of MINS in patients indicated for operation. Consistent with previous studies, (21, 22) a high TyG index is associated with MINS, even among patients without diabetes and with normal BMI. However, subgroup analysis suggests that the predictive value of the TyG index is weakened in patients with obesity, diabetes, and hypertension. These results may be attributed to differences in population characteristics and disease states, including cardiovascular system damage caused by hyperlipidaemia, diabetes, and hypertension, and the interference of therapeutic drugs (statins, antidiabetics, and antihypertensive drugs). Complex disease states may limit the predictive ability of the TyG index. In high-risk patients, individualised risk assessment requires a combination of multiple indicators to improve predictive accuracy.

During the feasibility validation phase, the research team observed that the detection rate of troponin among patients <40 years was too low to establish an effective analysis cohort.

Consequently, patients ≥40 years were focused upon, aligning with the Vascular Events in Surgery Patients Cohort Evaluation (VISION) study. (1) Although this approach may limit the generalizability of our findings, it enables our research to more accurately elucidate the practical value of the TyG index in the primary population experiencing postoperative ACEs. Current guidelines recommend troponin measurements (Class I recommendation) for patients who develop myocardial ischemia symptoms following non-cardiac surgeries. For those at high risk but without postoperative ischemic signs, a Class IIb recommendation is given. (23) This study limited its troponin measurements to patients with myocardial ischemia symptoms, potentially overlooking those with asymptomatic myocardial injury. Since asymptomatic myocardial injury is prevalent among postoperative patients, our study may not fully capture the potential association between the preoperative TyG index and asymptomatic myocardial injury. Larger-scale research is required to clarify the effects of TyG in various populations.

The association between the TyG index and MINS can be explained through atherosclerosis and metabolic abnormalities. The TyG index is a biomarker of metabolic disorders, and atherosclerotic and cardiovascular diseases. (16, 24, 25) It reflects the degree of CAD and is independently associated with coronary atherosclerosis in healthy adult populations. (9, 14) The TyG index is closely associated with insulin resistance (IR). (26-29) IR leads to endothelial dysfunction, increased inflammatory responses, accelerated foam cell formation, and smooth muscle cell proliferation, which promote atherosclerosis and vascular plaque formation. (30-32) Moreover, IR may reflect platelet reactivity and endothelial-dependent vasodilation. (33) The elevated preoperative TyG index is associated with hypertension, hyperglycaemia, and hyperlipidaemia, all of which enhance the risk of vascular inflammation, coagulation, and atherosclerosis. These mechanisms contribute to SCeMI (22). Perioperative hemodynamic changes, inflammatory responses, and oxidative stress may exacerbate pre-existing SCeMi, leading to MINS. Further investigations are needed to elucidate the exact mechanisms associating an elevated TyG index with MINS.

Preoperative troponin testing is not routine unless patients have a known history of CAD or exhibit symptoms of myocardial ischemia. The TyG index, more accessible than preoperative troponin, could serve as an alternative screening tool. It is associated with CAD severity, subclinical CAD, SCeMI, and MINS. Our findings suggest that a significantly elevated TyG value could be a

reliable marker for MINS risk. A high TyG index could be helpful for comprehensive preoperative assessments, including myocardial status evaluation and guidance for intervention strategies. For patients with a preoperative TyG index >8.73, additional measures such as troponin testing, coronary angiography, and medical therapy (such as stains and aspirin) should be considered, especially for those without a clear CAD history. Randomised controlled trials (RCTs) are necessary to verify whether these interventions can reduce postoperative ACEs.

Limitations

This retrospective study has several limitations. First, residual confounding factors may have introduced bias, such as excluding patients <40 years old and those lacking preoperative FBG and TG measurements. Second, preoperative troponin screening was not performed for all patients indicated for surgery, potentially missing those with preoperative myocardial injury and introducing selection bias. The high rate of missing HbA1c data led to its exclusion from the primary analysis. However, multivariate logistic regression analysis on the subset of data containing HbA1c yielded results consistent with the primary analysis (Supplementary Table S2). Third, our study focused solely on the association between baseline TyG index and MINS. Future RCTs are essential to determine the impact of variations in the TyG index on MINS prevention, mainly through preoperative interventions targeting lipid and glucose levels.

Conclusion

An elevated preoperative TyG index is positively associated with a higher incidence of MINS. It can be used to assess the risk of MINS preoperatively. Further research is required to determine if controlling and monitoring the TyG index can reduce postoperative ACEs.

Legends

Figure 1 Flowchart of the study population

Fig.1 Flow diagram illustrating the inclusion and exclusion of cases. TG: triglyceride.

Figure 2 RCS of TyG and MINS

Fig.2 The central heavy blue line represents the adjusted odds ratio, with shaded bands indicating the 95% CI. The horizontal dotted line represents an odds ratio of 1.0. The solid blue dot indicates the reference point for the TyG index (8.58). The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. RCS: restricted cubic

spline; TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

Figure 3 Post-hoc subgroup analysis

Fig.3 Forest plots depicting the relationship between the TyG index (≤8.73 and >8.73) and MINS. The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; OR: odds ratio; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

Abbreviations

MINS: Myocardial injury after noncardiac surgery

CAD: Coronary artery disease

SCeMI: Subclinical myocardial injury

ACEs: Adverse cardiovascular events

TG: Triglycerides

FBG: Fasting blood glucose

TyG index: Triglyceride-glucose index

cVRFs: Traditional cardiovascular risk factors

BMI: Body Mass Index

CAD: Coronary artery disease

CHF: Congestive heart failure

COPD: Chronic obstructive pulmonary disease

PVD: Peripheral vascular disease

Hb: Hemoglobin

eGFR: estimated Glomerular Filtration Rate

ASA: American Society of Anesthesiologists

HMR: heart rate to mean arterial pressure ratio

MINS: Myocardial injury after noncardiac surgery

ROC: Receiver operating characteristic

OR: Odds Ratio

CI: Confidence Interval

RCS: Restricted cubic spline

IR: insulin resistance

RCTs: randomized controlled trials

Ethics

The Ethical Review Board of Meizhou People's Hospital reviewed the study protocol and approved this retrospective cohort study, and informed consent was not required (Ethic No. 2023-C-92). We have also registered this study at the Chinese Clinical Trial Registry (No. ChiCTR2400082834).

Data availability statement

The corresponding author can grant data access to this study upon request.

Consent for publication

All authors revised the manuscript and approved the submission.

Competing interest

The authors have no conflicts of interest to declare.

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The research did not receive any external funding.

Patient and public involvement

This study did not involve members of the public or patients.

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Authors' contributions

Yuanjun Zhou: study design, data collection and examination, data analysis, and manuscript drafting, manuscript revision; Weiming Chen and Fei Liang: data examination and analysis, manuscript drafting, manuscript revision; Liping Zhong: data examination and data analysis; Yilin Liao: data examination and analysis and the supervision of the study process, manuscript revision; Yuting Zhong: study design, data collection, and examination, data analysis, manuscript drafting, manuscript revision and supervision of the study process.

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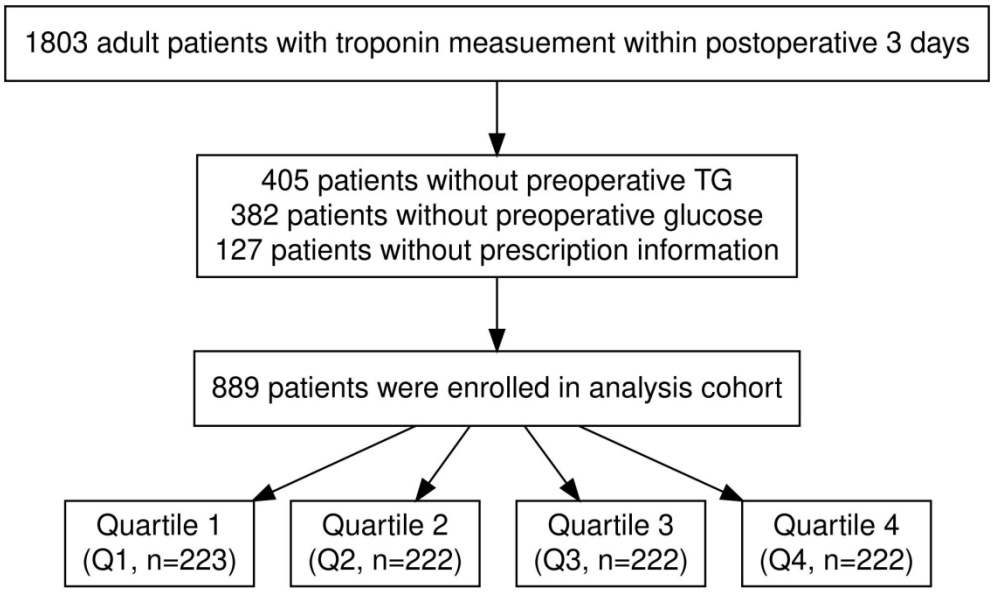

Figure 1 Flowchart of the study population
Fig.1 Flow diagram illustrating the inclusion and exclusion of cases. TG: triglyceride.

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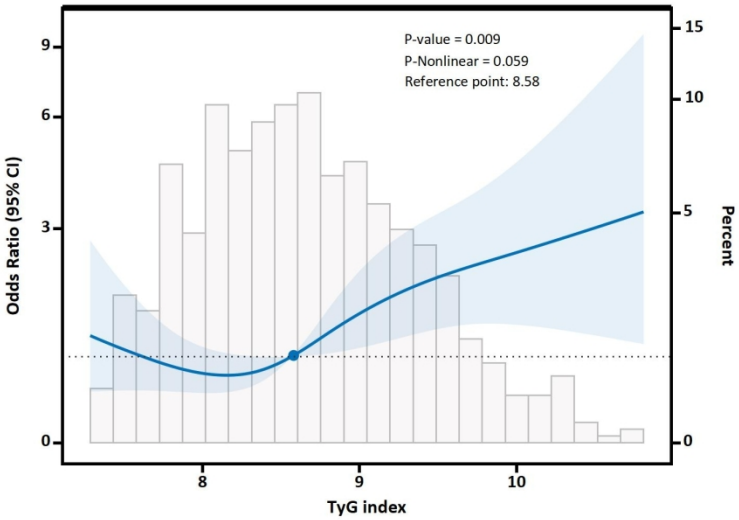

Figure 2 RCS of TyG and MINS

Fig.2 The central heavy blue line represents the adjusted odds ratio, with shaded bands indicating the 95% CI. The horizontal dotted line represents an odds ratio of 1.0. The solid blue dot indicates the reference point for the TyG index (8.58). The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. RCS: restricted cubic spline; TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

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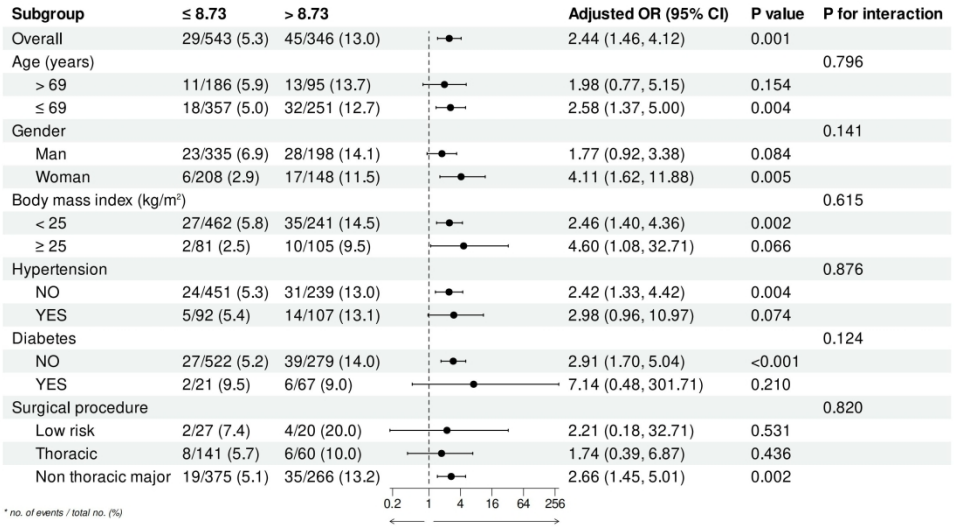


Figure 3 Post-hoc subgroup analysis

Fig.3 Forest plots depicting the relationship between the TyG index (≤8.73 and >8.73) and MINS. The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; OR: odds ratio; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

268x152mm (300 x 300 DPI)

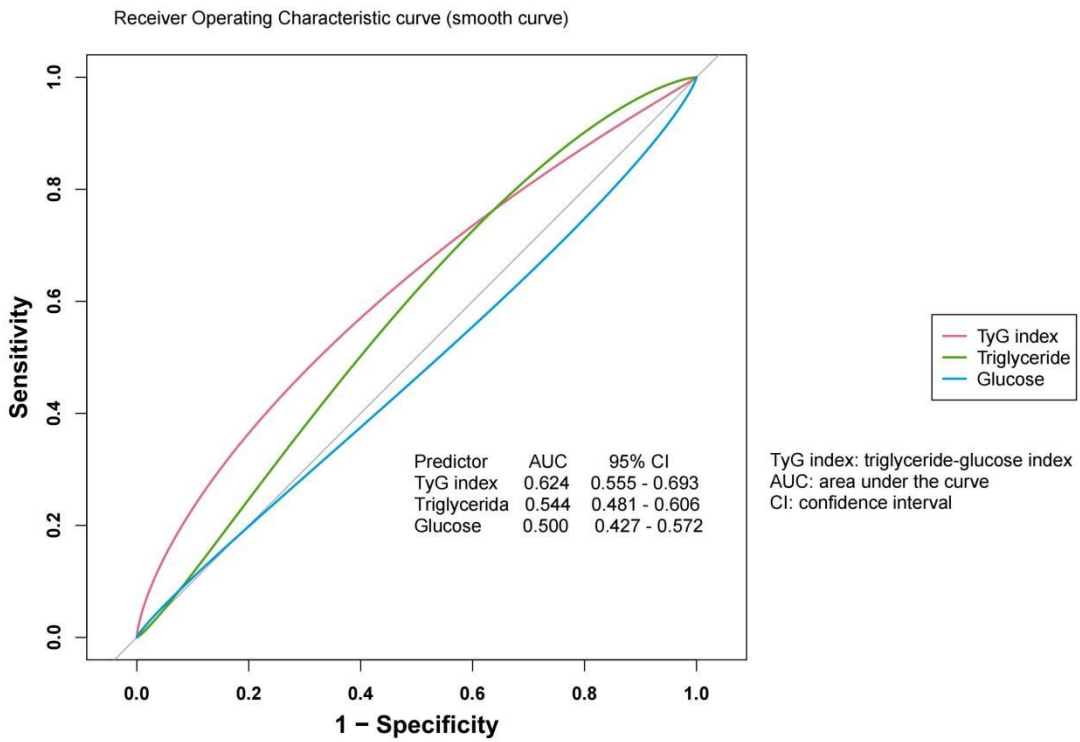
Supplementary materials

Supplementary Table S1 Baseline characteristics for patients stratified by MINS and non-MINS.

		MINS		
	Overall, N = 889	NO, N = 815	YES, N = 74	P
TyG index quartile	8.57 [8.13, 9.02]	8.54 [8.12, 9.00]	8.84 [8.41, 9.42]	<0.001
Age (years)	64 [55, 72]	64 [55, 72]	64 [58, 72]	0.215
Sex, male	533 (60.0)	482 (59.1)	51 (68.9)	0.100
BMI (kg/m^2)	22.1 [20.0, 24.6]	22.1 [20.0, 24.6]	22.8 [20.7, 24.4]	0.391
Preoperative Lab results				
Hemoglobin (g/L)	129 [112, 140]	129 [112, 140]	127 [111, 139]	0.440
eGFR (mL/min/1.73 m^2)	80 [68, 92]	81 [70, 92]	71 [54, 91]	0.002
Preoperative medical history				
CHF	19 (2.1)	16 (2.0)	3 (4.1)	0.205
Hypertension	199 (22.4)	180 (22.1)	19 (25.7)	0.478
CAD	43 (4.8)	37 (4.5)	6 (8.1)	0.161
COPD	71 (8.0)	60 (7.4)	11 (14.9)	0.023
Diabetes	88 (9.9)	80 (9.8)	8 (10.8)	0.784
Stroke	50 (5.6)	38 (4.7)	12 (16.2)	<0.001
PVD	58 (6.5)	46 (5.6)	12 (16.2)	0.002
Preoperative medications				
Rate-controlling	38 (4.3)	38 (4.7)	0 (0.0)	0.066
Aspirin	26 (2.9)	25 (3.1)	1 (1.4)	0.716
Heparin	164 (18.4)	148 (18.2)	16 (21.6)	0.462
Statins	81 (9.1)	69 (8.5)	12 (16.2)	0.027
ASA classification				0.717
I-II	57 (6.4)	54 (6.6)	3 (4.1)	
III	555 (62.4)	509 (62.5)	46 (62.2)	
IV-V	277 (31.2)	252 (30.9)	25 (33.8)	
Duration of anesthesia (mins)	200 [135, 260]	200 [135, 260]	185 [140, 260]	0.839
The highest intraoperative HMR	1.32 [1.13, 1.62]	1.32 [1.13, 1.61]	1.40 [1.10, 1.67]	0.497
Surgical procedures				0.390
Low-risk	47 (5.3)	41 (5.0)	6 (8.1)	
Thoracic	201 (22.6)	187 (22.9)	14 (18.9)	
Non-thoracic major	641 (72.1)	587 (72.0)	54 (73.0)	
Intraoperative bleeding (ml)	50 [20, 100]	50 [20, 100]	30 [20, 80]	0.402
Other variables				
TG (mg/dl)	1.19 [0.82, 1.68]	1.19 [0.82, 1.70]	1.10 [0.82, 1.55]	0.212
Glucose (mg/dl)	5.38 [4.65, 6.83]	5.37 [4.66, 6.82]	5.53 [4.56, 6.83]	0.997

Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; .BMI: Body Mass Index; eGFR: estimated Glomerular Filtration Rate (CKD-EPI formula); CHF: Congestive Heart Failure; CAD: Coronary Arterial Disease; COPD: Chronic Obstructive Pulmonary Disease; PVD: Peripheral Vascular Disease; ASA: American Society of Anesthesiologist. HMR: heart rate to mean arterial pressure.

Supplementary Figure S1



Supplementary Table S2 Univariate and multivariate logistic regression for TyG index and MINS

	Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Continuous TyG index per unit	2.993(1.732-5.172)	<0.001	3.527(1.797-6.922)	<0.001	4.041(1.900-8.596)	<0.001

Model 1: Crude; Model 2: Adjusted for age, gender, COPD, PVD, CAD, history of stroke, rate-controlling medications, statins, eGFR, HbA1c. Model 3: Adjust for age, gender, BMI, preoperative hemoglobin, eGFR, CHF, hypertension, CAD, COPD, diabetes, history of stroke, PVD, rate-controlling medications, aspirin, statins, ASA classification, duration of anesthesia, the highest intraoperative HMR, surgical procedures, intraoperative bleeding. Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; OR: Odds Ratio; CI: Confidence Interval; BMI: body mass index; eGFR: estimated glomerular filtration rate; CHF: congestive heart failure; CAD: coronary arterial disease; COPD: chronic obstructive pulmonary disease; PVD: peripheral vascular disease; ASA: American Society of Anesthesiologist; HMR: heart rate to mean arterial pressure.

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Title

Association between the preoperative triglyceride-glucose index and myocardial injury following noncardiac surgery: a retrospective study

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Abstract

Objective: An elevated triglyceride-glucose (TyG) index positively correlates with adverse cardiovascular events. However, its association with myocardial injury after noncardiac surgery (MINS) remains unclear. This study aimed to examine the association between the preoperative TyG index and MINS.

Design: a retrospective study

Setting: The cohort of adult patients were extracted from the electronic medical system of Meizhou People's Hospital.

Participants: Adult patients under general anaesthesia and with MINS.

Main exposure measure: The preoperative TyG index, calculated using triglyceride (TG) and fasting blood glucose (FBG) levels.

Main outcome measure: The occurrence of MINS, defined using postoperative troponin measurements.

Results: The final cohort included 889 patients, with an 8.3% incidence of MINS (74/889). The median TyG index was 8.57 [8.13, 9.02]. TyG exhibited higher discriminatory ability for MINS than TG and FBG, with an area under the curve (AUC) of 0.624, 0.544, and 0.500, respectively.

Fully adjusted logistic regression indicated that an elevated TyG index was independently associated with MINS (odds ratio 1.75, 95% confidence interval 1.21–2.52; P = 0.003). A multivariate restricted cubic spline suggested a linear relationship between TyG and MINS (P for nonlinearity = 0.059). Subgroup analyses showed results consistent with the primary analysis, with no significant interaction effects between subgroups.

Conclusion: An elevated preoperative TyG index is independently associated with an increased incidence of MINS. Monitoring the TyG index perioperatively may improve the management of patients at risk for MINS.

Keywords: triglyceride, blood glucose, troponin, noncardiac surgery, general anaesthesia

Strengths and limitations of this study

1. Postoperative troponin levels were utilized to diagnose myocardial injury after noncardiac surgery (MINS) to enhance the diagnostic objectivity and accuracy.

2. Multivariable-adjusted restricted cubic spline analysis was employed to examine the nonlinear association between baseline triglyceride-glucose (TyG) index and MINS.

3. Multivariable logistic regression analysis was conducted to investigate the association between the TyG index and MINS.

4. The study comprehensively evaluates the diagnostic performance and relationship between TyG and MINS.

5. It cannot establish a causal relationship between preoperative TyG and MINS due to the retrospective design.

Introduction

Myocardial injury after noncardiac surgery (MINS) occurs in approximately 3% to 16% of surgical cases [1-3], and is a significant cause of mortality within 30 days postoperatively [1, 4] . The pathophysiology of MINS includes the disruption of atherosclerotic coronary plaques and an imbalance between myocardial oxygen supply and demand. Preoperative coronary angiography is

not mandatory for individuals with coronary artery disease (CAD) who do not exhibit apparent myocardial ischemic symptoms, making it challenging to identify high-risk patients preoperatively. Therefore, clinicians need a convenient and practical index for this purpose. Significant risk factors for CAD include dyslipidaemia and hyperglycaemia. Both obesity [5] and hyperglycaemia [6] have been strongly associated with subclinical myocardial injury (SCeMI), and adverse cardiovascular events (ACEs).

The triglyceride-glucose (TyG) index, derived from triglycerides (TG) and fasting blood glucose (FBG), has been linked to the severity of CAD and ACEs [7-10]. Elevated TyG index levels are associated with increased severity of coronary artery stenosis and a higher number of diseased vessels in patients with acute coronary syndrome (ACS) [11, 12]. The TyG index is a robust predictor of subclinical CAD, even without traditional cardiovascular risk factors (CVRFs) [13]. Furthermore, Kim et al. demonstrated a correlation between higher TyG index levels and the presence of coronary artery calcification plaques in healthy adults [14]. This observation suggests that patients indicated for operation who have a high TyG index and undergo general anaesthesia may possess underlying coronary artery atherosclerosis and a heightened risk of MINS, regardless of CVRFs. Since dyslipidaemia and hyperglycaemia are routinely detectable and modifiable preoperatively, understanding the relationship between MINS and the TyG index is crucial for perioperative management. However, there is limited research on this issue. Therefore, the clinical records from Meizhou People's Hospital were reviewed to investigate whether preoperative TyG levels were associated with MINS. Elevated preoperative TyG index was hypothesised as an independent risk factor for developing MINS.

Methods and materials

Ethics

The Ethical Review Board of Meizhou People's Hospital approved this retrospective cohort study, and informed consent was waived (Ethic No. 2023-C-92). This study is registered with the Chinese Clinical Trial Registry (No. ChiCTR2400082834).

Data Source

This retrospective study utilised medical records from Meizhou People's Hospital, including the Electronic Medical Record System, Surgical Anaesthesia System, Prescription System, and Laboratory and Examination Systems. The Department of Medical Data and the Department of

Medical Administration granted access to these records. Weiming Chen and Fei Liang were responsible for data extraction and cleaning, adhering to the study protocol.

Study Population

Inclusion Criteria: Patients indicated for operation aged ≥40 years, who were administered general anaesthesia and those with troponin measurements recorded within three postoperative days. Exclusion Criteria: (1) Patients <40 years; (2) Patients admitted without FBG and TG measurements; (3) Patients lacking prescription information.

Exposure of interest

The primary exposure was the preoperative TyG index., calculated using the formula: TyG = ln (TG [mg/dL] × FBG [mg/dL] /2) [15, 16]. The conversion formulas used were FBG (mg/dL) = FBG (mmol/L) × 18.0 and TG (mg/dL) = TG (mmol/L) × 88.6. If FBG and TG were measured multiple times preoperatively, the closest measurements to the operation time were utilised.

Variables

The potential variables were categorised into four groups: (1) demographic characteristics, including age, gender, and body mass index (BMI); (2) preoperative comorbidities, including congestive heart failure (CHF), hypertension, CAD, chronic obstructive pulmonary disease (COPD), diabetes, history of stroke, and peripheral vascular disease (PVD); (3) preoperative laboratory results, including haemoglobin (Hb) and estimated glomerular filtration rate (eGFR); (4) surgical information, including the American Society of Anesthesiologists (ASA) Physical Status Classification System, highest intraoperative heart rate to mean arterial pressure (HMR), duration of anaesthesia, and surgical categories.

Outcomes

The outcome of interest was MINS, defined by postoperative troponin levels exceeding the 99th percentile upper reference limit without nonischaemic causes [17, 18].

Statistical Analysis

This retrospective study included as many individuals as possible; therefore, no power calculation was conducted. The random forest algorithm was used for multiple imputations of variables with <20% missing data. Variables with >20% missing data were excluded to avoid bias. Patients were categorised into four groups based on the TyG index quartiles. Categorical variables were expressed as proportions. Chi-square tests, Fisher's exact test, were used for unordered

categorical variables, and Kruskal-Wallis tests for ordered categorical variables. Continuous variables, expressed as median (interquartile range [IQR]) due to non-normal distribution (per Shapiro–Wilk test), were analysed using the Mann–Whitney U test or Kruskal–Wallis rank sum tests. The diagnostic performance of TyG for MINS was assessed using receiver operating characteristic (ROC) curves to determine the best cutoff value. Logistic regression analysis identified factors influencing MINS across three models: Model 1: Unadjusted; Model 2: Adjusted for variables with a P-value <0.2 in the univariate analysis, along with clinically relevant variables; Model 3: Adjusted for all predefined variables. Odds ratio (OR) and 95% confidence intervals (CI) were calculated for TyG and the outcome. The linear trend (P trend) was assessed, and a multivariate restricted cubic spline (RCS) model analysed the nonlinear relationship between baseline TyG and MINS. Post-hoc subgroup analyses were stratified by age (≤69 years and >69 years), gender, BMI (<25 and ≥25 kg/m^2), hypertension, and surgical category, with interaction effects tested between subgroups.

A P-value <0.05 indicated statistical significance in two-tailed tests. Based on the open-source R, all statistical analyses were conducted using Stata software (https://www.mstata.com/).

Patient and public involvement

This study did not involve members of the public or patients.

Results

Reporting guideline

This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [19].

Cohort characteristics

A total of 889 patients undergoing general anaesthesia were included in the study (Figure 1). Patients were categorised into four groups based on their TyG index (Table 1). The TyG ranges for each group are specified in Table 1. More than half of the patients were men, with a median age of 64 years. The overall median TyG index for all patients was 8.57, and the incidence of MINS was 8.3%. The fourth quartile (Q4) group generally exhibited a higher BMI and a higher prevalence of preoperative hypertension, diabetes, and history of stroke. Patients with a lower TyG index exhibited a lower incidence of MINS than those with a higher TyG index (P = 0.009).

Table 1 Baseline characteristics for patients stratified by TyG index quartiles.

	Overall, N = 889	Q1, N = 223	Q2, N = 222	Q3, N = 222	Q4, N = 222	P
TyG index range	5.03 - 11.33	5.03 - 8.13	8.14 - 8.57	8.58 - 9.02	9.03 - 11.33	/
TyG index quartile	8.57 [8.13, 9.02]	7.85 [7.71, 8.03]	8.37 [8.25, 8.47]	8.75 [8.65, 8.89]	9.44 [9.21, 9.75]	<0.001
Age (years)	64 [55, 72]	64 [55, 73]	64 [55, 72]	65 [58, 73]	60 [54, 69]	<0.001
Sex, man	533 (60.0)	137 (61.4)	148 (66.7)	115 (51.8)	133 (59.9)	0.015
BMI (kg/m^2)	22.1 [20.0, 24.6]	20.4 [18.7, 22.5]	21.9 [19.7, 24.0]	22.8 [20.8, 25.1]	23.5 [21.3, 25.5]	<0.001
Preoperative Lab results						
Hemoglobin (g/L)	129 [112, 140]	124 [109, 137]	128 [112, 138]	130 [116, 140]	131 [114, 145]	0.010
eGFR (mL/min/1.73 m^2)	80 [68, 92]	81 [70, 93]	80 [70, 91]	78 [65, 91]	81 [68, 96]	0.220
Preoperative medical history						
CHF	19 (2.1)	4 (1.8)	4 (1.8)	7 (3.2)	4 (1.8)	0.753
Hypertension	199 (22.4)	27 (12.1)	40 (18.0)	60 (27.0)	72 (32.4)	<0.001
CAD	43 (4.8)	9 (4.0)	7 (3.2)	17 (7.7)	10 (4.5)	0.135
COPD	71 (8.0)	23 (10.3)	21 (9.5)	17 (7.7)	10 (4.5)	0.112
Diabetes	88 (9.9)	4 (1.8)	12 (5.4)	22 (9.9)	50 (22.5)	<0.001
Stroke	50 (5.6)	4 (1.8)	12 (5.4)	11 (5.0)	23 (10.4)	0.001
PVD	58 (6.5)	11 (4.9)	13 (5.9)	18 (8.1)	16 (7.2)	0.538
Preoperative medications						
Rate-controlling	38 (4.3)	9 (4.0)	8 (3.6)	14 (6.3)	7 (3.2)	0.362
Aspirin	26 (2.9)	6 (2.7)	6 (2.7)	7 (3.2)	7 (3.2)	0.983
Statins	81 (9.1)	16 (7.2)	18 (8.1)	25 (11.3)	22 (9.9)	0.442
ASA classification						0.888
I-II	57 (6.4)	12 (5.4)	17 (7.7)	13 (5.9)	15 (6.8)	
III	555 (62.4)	141 (63.2)	139 (62.6)	143 (64.4)	132 (59.5)	
IV-V	277 (31.2)	70 (31.4)	66 (29.7)	66 (29.7)	75 (33.8)	
Duration of anaesthesia (mins)	200 [135, 260]	205 [140, 266]	200 [135, 274]	205 [140, 259]	184 [135, 245]	0.134
The highest intraoperative	1.32 [1.13, 1.62]	1.30 [1.10, 1.54]	1.32 [1.11, 1.64]	1.33 [1.16, 1.65]	1.33 [1.15, 1.65]	0.248
HMR						
Surgical procedures						0.002
Low-risk	47 (5.3)	12 (5.4)	13 (5.9)	3 (1.4)	19 (8.6)	
Thoracic	201 (22.6)	60 (26.9)	55 (24.8)	53 (23.9)	33 (14.9)	
Non-thoracic major	641 (72.1)	151 (67.7)	154 (69.4)	166 (74.8)	170 (76.6)	
Intraoperative bleeding (ml)	50 [20, 100]	50 [20, 100]	50 [20, 100]	50 [20, 100]	50 [15, 100]	0.405
Outcomes						
MINS within postoperative 3 days	74 (8.3)	10 (4.5)	15 (6.8)	20 (9.0)	29 (13.1)	0.009
Other variables						
TG (mmol/L)	1.19 [0.82, 1.68]	0.70 [0.59, 0.82]	1.04 [0.90, 1.22]	1.46 [1.20, 1.70]	2.16 [1.65, 3.07]	<0.001
Glucose (mmol/L)	5.38 [4.65, 6.83]	4.63 [4.15, 5.30]	5.13 [4.60, 6.04]	5.52 [4.96, 6.63]	7.22 [5.73, 10.25]	<0.001

Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; .BMI: Body Mass Index; eGFR: estimated Glomerular Filtration Rate (CKD-EPI formula); CHF: Congestive Heart Failure; CAD: Coronary Arterial Disease; COPD: Chronic Obstructive Pulmonary Disease; PVD: Peripheral Vascular Disease; ASA: American Society of Anesthesiologist. HMR: heart rate to mean arterial pressure.

Baseline Characteristics of Patients with and without MINS

Supplementary Table S1 details the differences between the MINS and non-MINS groups. The median TyG index was significantly higher in the MINS group than in the non-MINS group (P<0.001). The two groups significantly differed in preoperative eGFR (P = 0.002). Moreover, the MINS group exhibited a significantly higher occurrence of COPD, a history of stroke, and PVD. Preoperative statin use was significantly lower in the non-MINS group (P = 0.027).

ROC Analysis

The TyG index demonstrated higher discriminatory accuracy for MINS than TG and FBG, with an area under the curve (AUC) of 0.624, 0.544, and 0.500, respectively (Supplementary Figure S1). The optimal cutoff value for the TyG index was identified as 8.73 (63.2% specificity and 60.8% sensitivity).

Multivariable Logistic Regression

The continuous TyG index was positively associated with MINS in the crude and adjusted models (Table 2). Neither the Q2 nor the Q3 group exhibited a significantly different risk of MINS than the Q1 group. However, the Q4 group exhibited a substantially increased risk of MINS across all models. A significant linear (P) trend was observed across models 1, 2, and 3.

Table 2 Univariate and multivariate logistic regression for TyG index and MINS

	Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Continuous TyG index per unit	1.72 (1.27 - 2.35)	<0.001	1.54 (1.11 - 2.15)	0.010	1.75 (1.21 - 2.52)	0.003
TyG index quartile group (range)						
Q1 (5.03-8.13)	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2 (8.14-8.57)	1.54 (0.68 - 3.51)	0.301	1.27 (0.55 - 2.98)	0.575	1.44 (0.61 - 3.42)	0.404
Q3 (8.58-9.02)	2.11 (0.96 - 4.61)	0.062	1.90 (0.85 - 4.27)	0.118	2.21 (0.95 - 5.17)	0.066
Q4 (9.03–11.33)	3.20 (1.52 - 6.74)	0.002	2.63 (1.20 - 5.78)	0.016	3.37 (1.46 - 7.81)	0.005
P_{trend}	<0.001		0.006		0.002	

Model 1: Crude; Model 2: Adjusted for age, gender, COPD, PVD, CAD, history of stroke, rate-controlling medications, statins, and eGFR. Model 3: Adjust for age, gender, BMI, preoperative hemoglobin, eGFR, CHF, hypertension, CAD, COPD, diabetes, history of stroke, PVD, rate-controlling medications, aspirin, statins, ASA classification, duration of anesthesia, the highest intraoperative HMR, surgical procedures, intraoperative bleeding. Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; OR: Odds Ratio; CI: Confidence Interval; BMI: body mass index; eGFR: estimated glomerular filtration rate; CHF: congestive heart failure; CAD: coronary arterial disease; COPD: chronic obstructive pulmonary disease; PVD: peripheral vascular disease; ASA: American Society of Anesthesiologist; HMR: heart rate to mean arterial pressure.

RCS Analysis

The RCS analysis revealed a linear increase in the risk of MINS with rising TyG index values (P for nonlinear = 0.059) (Figure 2). The reference point was set at 8.58, consistent with the optimal cutoff value of 8.73 derived from the ROC analysis.

Subgroup analysis

For clinical application, patients were categorised into two groups based on the TyG index (≤8.73 vs. >8.73) to examine subgroup heterogeneity (Figure 3). A TyG index >8.73 was particularly prominent in the following subgroups: patients ≤69 years, female patients, patients with a BMI <25 kg/m², patients without hypertension, and patients undergoing non-thoracic surgery. There was no considerable interaction effect among these subgroups.

Discussion

This study reveals that an elevated preoperative TyG index is independently associated with MINS. Our research provides a novel perspective for risk stratification and management strategies related to MINS. Previous research on the relationship between the preoperative TyG index and postoperative ACEs has been limited.

The TyG index demonstrates greater clinical utility than the homeostasis model assessment of insulin resistance (HOMA-IR) for evaluating insulin resistance (IR) and predicting metabolic disease risk [20]. Its key advantage lies in operational efficiency: HOMA-IR requires fasting insulin measurements, which are often unavailable in low-resource settings, thereby limiting its clinical accessibility. In contrast, the TyG index can be calculated using two routinely measured preoperative parameters - TG and FBG. Recent studies have confirmed a significant positive association between elevated TyG index and several cardiovascular disorders [21], including heart failure [22], ACS and CAD [9, 23], arterial stiffness [24], stroke [25, 26], ACEs [27], and atrial fibrillation [28]. However, the relationship between the preoperative TyG index and MINS remains ambiguous. According to Liu et al., the TyG index is a significant biomarker of SCeMI [29]. Similarly, our study demonstrates a correlation between an elevated preoperative TyG index and a greater risk of MINS, complementing these findings. Compared to FBG and TG, the TyG index demonstrates more robust diagnostic efficacy for MINS, possibly because it more comprehensively reflects the body's metabolic status and arterial disease state. The linear association between the preoperative TyG index and MINS suggests that the TyG index could be used to predict the incidence of MINS in patients indicated for operation. Consistent with previous studies [29, 30], a

high TyG index is associated with MINS, even among patients without diabetes and with normal BMI. However, subgroup analysis suggests that the predictive value of the TyG index is weakened in patients with obesity, diabetes, and hypertension. These results may be attributed to differences in population characteristics and disease states, including cardiovascular system damage caused by hyperlipidaemia, diabetes, and hypertension, and the interference of therapeutic drugs (statins, antidiabetics, and antihypertensive drugs). Complex disease states may limit the predictive ability of the TyG index. In high-risk patients, individualised risk assessment requires a combination of multiple indicators to improve predictive accuracy.

Emerging evidence aligns with our findings, demonstrating that the atherogenic index of plasma (AIP) independently predicts MINS [31]. These investigations synergistically highlight the clinical utility of preoperative metabolic profiling for stratifying postoperative ACEs. Whereas the AIP study focused specifically on the TG-to-high density lipoprotein ratio as a lipid-centric predictor, our TyG index analysis extends this paradigm by evaluating the combined contribution of TG and glucose metabolism to perioperative cardiovascular risk. This complementary approach strengthens the rationale for incorporating multidimensional metabolic assessments into preoperative evaluation of postoperative ACEs. Our findings not only validate the TyG index's predictive capacity but crucially extend its clinical application through population diversification. Our results align with a prior evidence demonstrating the TyG index's association with MINS in geriatric populations (⩾65 years) [32]. Notably, our investigation extends beyond this demographic by encompassing younger surgical cohorts (40-65 years), thereby broadening the validated clinical applicability of the TyG index across age groups underrepresented in existing MINS research. This expanded patient spectrum addresses a critical knowledge gap, as current study predominantly focuses on elderly populations despite the growing prevalence of cardiovascular risk factors in younger adults [1, 17, 33]. Moreover, our study advances the field by establishing a linear dose-response relationship between TyG index values and MINS risk - a finding not previously quantified in earlier investigations. These methodological refinements strengthen the TyG index's utility for preoperative risk stratification in diverse surgical populations.

The association between the TyG index and MINS can be explained through atherosclerosis and metabolic abnormalities. The TyG index is a biomarker of metabolic disorders, and atherosclerotic and cardiovascular diseases [16, 34, 35]. It reflects the degree of CAD and is

independently associated with coronary atherosclerosis in healthy adult populations [9, 14]. The TyG index is closely associated with IR [36-39]. IR leads to endothelial dysfunction, increased inflammatory responses, accelerated foam cell formation, and smooth muscle cell proliferation, which promote atherosclerosis and vascular plaque formation [40, 41]. Moreover, IR may reflect platelet reactivity and endothelial-dependent vasodilation [42]. The elevated preoperative TyG index is associated with hypertension, hyperglycaemia, and hyperlipidaemia, all of which enhance the risk of vascular inflammation, coagulation, and atherosclerosis. These mechanisms contribute to SCeMI [29]. Perioperative hemodynamic changes, inflammatory responses, and oxidative stress may exacerbate pre-existing SCeMi, leading to MINS. Further investigations are needed to elucidate the exact mechanisms associating an elevated TyG index with MINS.

This study highlights the clinical utility of the preoperative TyG index as a simple, cost-effective tool for identifying patients at elevated risk of MINS. Preoperative troponin testing is not routine unless patients have a known history of CAD or exhibit symptoms of myocardial ischemia. The TyG index, more accessible than preoperative troponin, could serve as an alternative screening tool. It is associated with CAD severity, subclinical CAD, SCeMI, and MINS. Clinicians should consider incorporating TyG index screening into preoperative assessments for patients aged $\geqslant$40 years undergoing general anaesthesia, particularly those without overt cardiovascular symptoms. A high TyG index could be helpful for preoperative assessments, including preoperative myocardial status evaluation and guidance for intervention strategies (e.g., glycaemic control and lipid management). For patients with a preoperative TyG index >8.73, heightened vigilance is warranted, including troponin testing, coronary angiography, and medical therapy (such as statins and aspirin), especially for those without a clear CAD history. Our findings suggest that preoperative TyG index evaluation could refine perioperative risk stratification and guide targeted interventions to mitigate MINS-related complications. Randomised controlled trials (RCTs) are necessary to verify the optimal strategies based on the preoperative TyG index evaluation.

Limitations

This retrospective study has several limitations. First, residual confounding factors may have introduced bias, such as excluding patients <40 years old and those lacking preoperative FBG and TG measurements. Second, preoperative troponin screening was not performed for all patients indicated for surgery, potentially missing those with preoperative myocardial injury and introducing

selection bias. This study limited its troponin measurements to patients with myocardial ischemia symptoms. Since asymptomatic myocardial injury is prevalent among postoperative patients, our study may not fully capture the potential association between the preoperative TyG index and asymptomatic myocardial injury. Current guidelines recommend troponin measurements (Class I recommendation) for patients who develop myocardial ischemia symptoms following non-cardiac surgeries. For those at high risk but without postoperative ischemic signs, a Class IIb recommendation is given [43]. The high rate of missing HbA1c data led to its exclusion from the primary analysis. However, multivariate logistic regression analysis on the subset of data containing HbA1c yielded results consistent with the primary analysis (Supplementary Table S2). Third, our study focused solely on the association between baseline TyG index and MINS. Future RCTs are essential to determine the impact of variations in the TyG index on MINS prevention, mainly through preoperative interventions targeting lipid and glucose levels.

Conclusion

An elevated preoperative TyG index is positively associated with a higher incidence of MINS. It can be used to assess the risk of MINS preoperatively. Further research is required to determine if controlling and monitoring the TyG index can reduce postoperative ACEs.

Legends

Figure 1 Flowchart of the study population

Fig.1 Flow diagram illustrating the inclusion and exclusion of cases. TG: triglyceride.

Figure 2 RCS of TyG and MINS

Fig.2 The central heavy blue line represents the adjusted odds ratio, with shaded bands indicating the 95% CI. The horizontal dotted line represents an odds ratio of 1.0. The solid blue dot indicates the reference point for the TyG index (8.58). The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. RCS: restricted cubic spline; TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

Figure 3 Post-hoc subgroup analysis

Fig.3 Forest plots depicting the relationship between the TyG index (≤8.73 and >8.73) and

MINS. The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; OR: odds ratio; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

Abbreviations

MINS: Myocardial injury after noncardiac surgery

CAD: Coronary artery disease

SCeMI: Subclinical myocardial injury

ACEs: Adverse cardiovascular events

TG: Triglycerides

FBG: Fasting blood glucose

ACS: Acute Coronary Syndrome

TyG index: Triglyceride-glucose index

cVRFs: Traditional cardiovascular risk factors

BMI: Body Mass Index

CAD: Coronary artery disease

CHF: Congestive heart failure

COPD: Chronic obstructive pulmonary disease

PVD: Peripheral vascular disease

Hb: Hemoglobin

eGFR: estimated Glomerular Filtration Rate

ASA: American Society of Anesthesiologists

HMR: heart rate to mean arterial pressure ratio

MINS: Myocardial injury after noncardiac surgery

ROC: Receiver operating characteristic

OR: Odds Ratio

CI: Confidence Interval

RCS: Restricted cubic spline

HOMA-IR: Homeostasis model assessment of insulin resistance

IR: insulin resistance

AIP: Atherogenic index of plasma

RCTs: randomized controlled trials

Ethics

The Ethical Review Board of Meizhou People's Hospital reviewed the study protocol and approved this retrospective cohort study, and informed consent was not required (Ethic No. 2023-C-92). We have also registered this study at the Chinese Clinical Trial Registry (No. ChiCTR2400082834).

Data availability statement

The corresponding author can grant data access to this study upon request.

Consent for publication

All authors revised the manuscript and approved the submission.

Competing interest

The authors have no conflicts of interest to declare.

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Patient and public involvement

This study did not involve members of the public or patients.

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Authors' contributions

Yuanjun Zhou: study design, data collection and examination, data analysis, and manuscript

drafting, manuscript revision; Weiming Chen and Fei Liang: data examination and analysis, manuscript drafting, manuscript revision; Liping Zhong: data examination and data analysis; Yilin Liao: data examination and analysis and the supervision of the study process, manuscript revision; Yuting Zhong (guarantor): study design, data collection, and examination, data analysis, manuscript drafting, manuscript revision and supervision of the study process.

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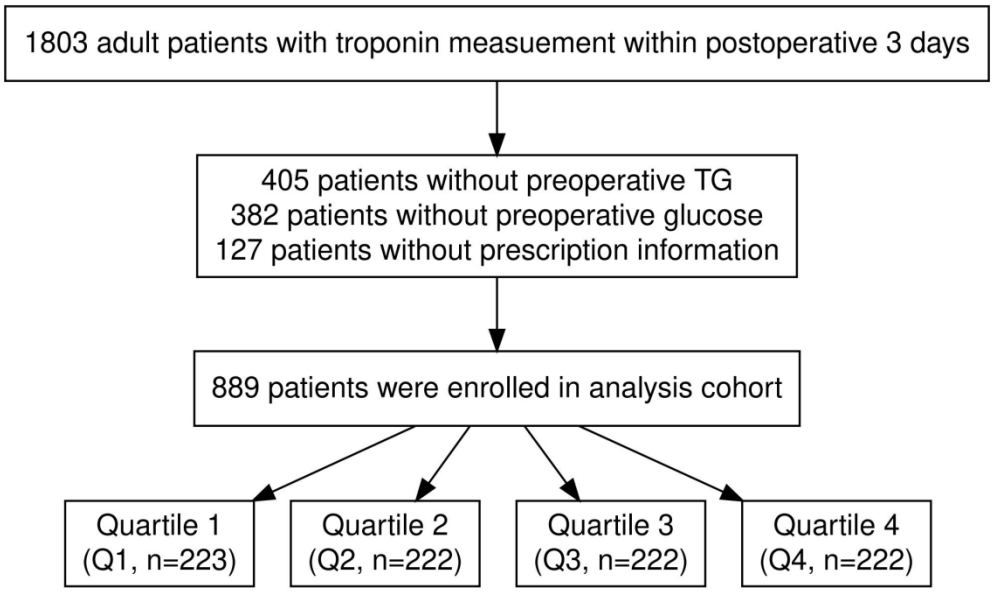

Figure 1 Flowchart of the study population
Fig.1 Flow diagram illustrating the inclusion and exclusion of cases. TG: triglyceride.

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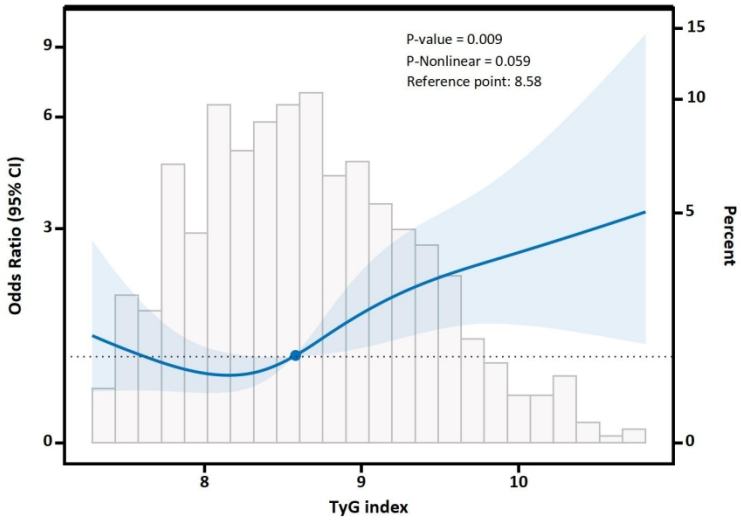

Figure 2 RCS of TyG and MINS

Fig.2 The central heavy blue line represents the adjusted odds ratio, with shaded bands indicating the 95% CI. The horizontal dotted line represents an odds ratio of 1.0. The solid blue dot indicates the reference point for the TyG index (8.58). The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. RCS: restricted cubic spline; TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

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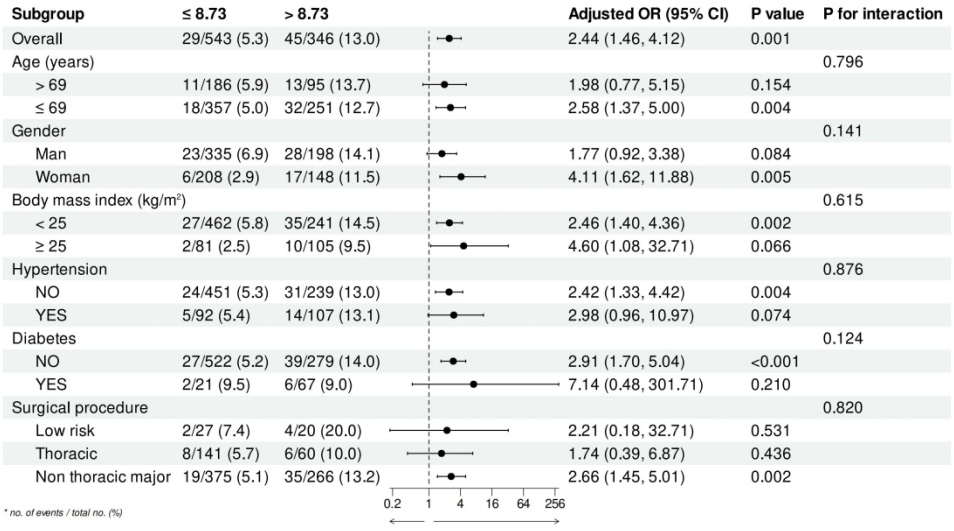


Figure 3 Post-hoc subgroup analysis

Fig.3 Forest plots depicting the relationship between the TyG index (≤8.73 and >8.73) and MINS. The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; OR: odds ratio; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

268x152mm (300 x 300 DPI)

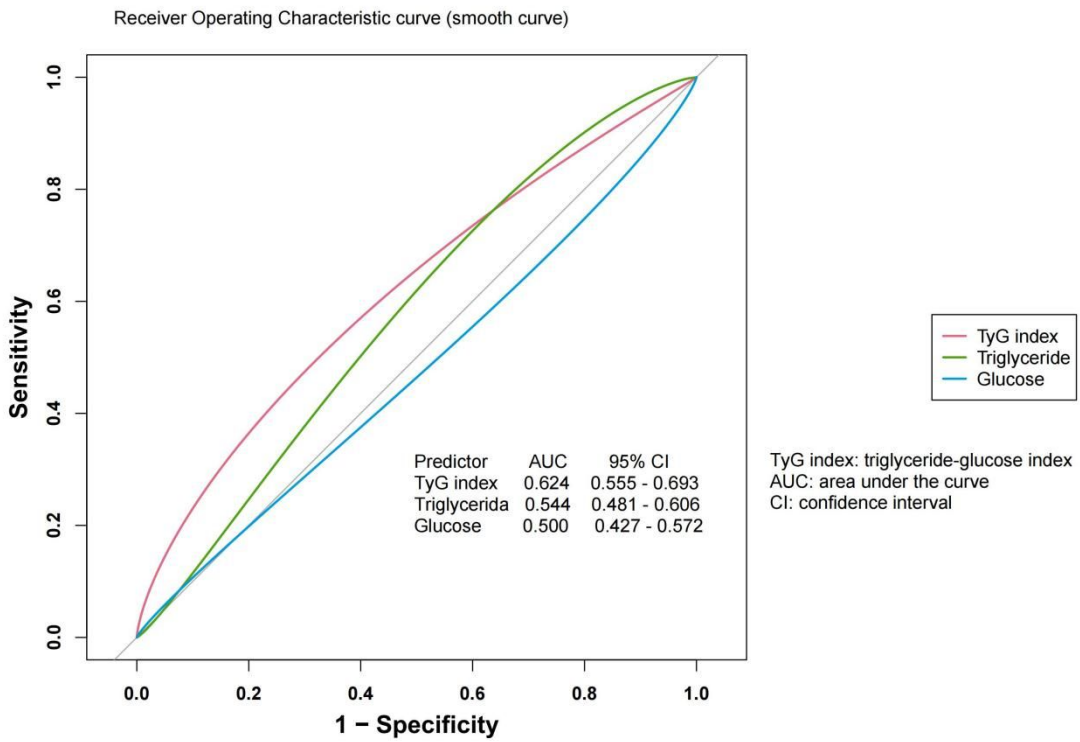
Supplementary materials

Supplementary Table S1 Baseline characteristics for patients stratified by MINS and non-MINS.

		MINS		
	Overall, N = 889	NO, N = 815	YES, N = 74	P
TyG index quartile	8.57 [8.13, 9.02]	8.54 [8.12, 9.00]	8.84 [8.41, 9.42]	<0.001
Age (years)	64 [55, 72]	64 [55, 72]	64 [58, 72]	0.215
Sex, male	533 (60.0)	482 (59.1)	51 (68.9)	0.100
BMI (kg/m^2)	22.1 [20.0, 24.6]	22.1 [20.0, 24.6]	22.8 [20.7, 24.4]	0.391
Preoperative Lab results				
Hemoglobin (g/L)	129 [112, 140]	129 [112, 140]	127 [111, 139]	0.440
eGFR (mL/min/1.73 m^2)	80 [68, 92]	81 [70, 92]	71 [54, 91]	0.002
Preoperative medical history				
CHF	19 (2.1)	16 (2.0)	3 (4.1)	0.205
Hypertension	199 (22.4)	180 (22.1)	19 (25.7)	0.478
CAD	43 (4.8)	37 (4.5)	6 (8.1)	0.161
COPD	71 (8.0)	60 (7.4)	11 (14.9)	0.023
Diabetes	88 (9.9)	80 (9.8)	8 (10.8)	0.784
Stroke	50 (5.6)	38 (4.7)	12 (16.2)	<0.001
PVD	58 (6.5)	46 (5.6)	12 (16.2)	0.002
Preoperative medications				
Rate-controlling	38 (4.3)	38 (4.7)	0 (0.0)	0.066
Aspirin	26 (2.9)	25 (3.1)	1 (1.4)	0.716
Heparin	164 (18.4)	148 (18.2)	16 (21.6)	0.462
Statins	81 (9.1)	69 (8.5)	12 (16.2)	0.027
ASA classification				0.717
I-II	57 (6.4)	54 (6.6)	3 (4.1)	
III	555 (62.4)	509 (62.5)	46 (62.2)	
IV-V	277 (31.2)	252 (30.9)	25 (33.8)	
Duration of anesthesia (mins)	200 [135, 260]	200 [135, 260]	185 [140, 260]	0.839
The highest intraoperative HMR	1.32 [1.13, 1.62]	1.32 [1.13, 1.61]	1.40 [1.10, 1.67]	0.497
Surgical procedures				0.390
Low-risk	47 (5.3)	41 (5.0)	6 (8.1)	
Thoracic	201 (22.6)	187 (22.9)	14 (18.9)	
Non-thoracic major	641 (72.1)	587 (72.0)	54 (73.0)	
Intraoperative bleeding (ml)	50 [20, 100]	50 [20, 100]	30 [20, 80]	0.402
Other variables				
TG (mg/dl)	1.19 [0.82, 1.68]	1.19 [0.82, 1.70]	1.10 [0.82, 1.55]	0.212
Glucose (mg/dl)	5.38 [4.65, 6.83]	5.37 [4.66, 6.82]	5.53 [4.56, 6.83]	0.997

Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; .BMI: Body Mass Index; eGFR: estimated Glomerular Filtration Rate (CKD-EPI formula); CHF: Congestive Heart Failure; CAD: Coronary Arterial Disease; COPD: Chronic Obstructive Pulmonary Disease; PVD: Peripheral Vascular Disease; ASA: American Society of Anesthesiologist. HMR: heart rate to mean arterial pressure.

Supplementary Figure S1



Supplementary Table S2 Univariate and multivariate logistic regression for TyG index and MINS

	Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Continuous TyG index per unit	2.993(1.732-5.172)	<0.001	3.527(1.797-6.922)	<0.001	4.041(1.900-8.596)	<0.001

Model 1: Crude; Model 2: Adjusted for age, gender, COPD, PVD, CAD, history of stroke, rate-controlling medications, statins, eGFR, HbA1c. Model 3: Adjust for age, gender, BMI, preoperative hemoglobin, eGFR, CHF, hypertension, CAD, COPD, diabetes, history of stroke, PVD, rate-controlling medications, aspirin, statins, ASA classification, duration of anesthesia, the highest intraoperative HMR, surgical procedures, intraoperative bleeding. Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; OR: Odds Ratio; CI: Confidence Interval; BMI: body mass index; eGFR: estimated glomerular filtration rate; CHF: congestive heart failure; CAD: coronary arterial disease; COPD: chronic obstructive pulmonary disease; PVD: peripheral vascular disease; ASA: American Society of Anesthesiologist; HMR: heart rate to mean arterial pressure.

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Title

Association between the preoperative triglyceride-glucose index and myocardial injury following noncardiac surgery: a cross-sectional study

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Abstract

Objective: An elevated triglyceride-glucose (TyG) index positively correlates with adverse cardiovascular events. However, its association with myocardial injury after noncardiac surgery (MINS) remains unclear. This study aimed to examine the association between the preoperative TyG index and MINS.

Design: a cross-sectional study

Setting: Meizhou People's Hospital.

Participants: Adult patients under general anaesthesia and with MINS.

Main exposure measure: The preoperative TyG index, calculated using triglyceride (TG) and fasting blood glucose (FBG) levels.

Main outcome measure: The occurrence of MINS, defined using postoperative troponin measurements.

Results: 889 patients were included, with an 8.3% incidence of MINS (74/889). The median TyG index was 8.57 [8.13, 9.02]. TyG exhibited higher discriminatory ability for MINS than TG and FBG, with an area under the curve (AUC) of 0.624, 0.544, and 0.500, respectively. Fully adjusted logistic regression indicated that an elevated TyG index was independently associated with MINS

(odds ratio 1.75, 95% confidence interval 1.21–2.52; P = 0.003). A multivariate restricted cubic spline suggested a linear relationship between TyG and MINS (P for nonlinearity = 0.059). Subgroup analyses showed results consistent with the primary analysis, with no significant interaction effects between subgroups.

Conclusion: An elevated preoperative TyG index is independently associated with an increased incidence of MINS. Monitoring the TyG index perioperatively may improve the management of patients at risk for MINS.

Keywords: triglyceride, blood glucose, troponin, noncardiac surgery, general anaesthesia

Strengths and limitations of this study

1. Postoperative troponin levels were utilized to diagnose myocardial injury after noncardiac surgery (MINS) to enhance the diagnostic objectivity and accuracy.

2. We demonstrated a nonlinear and independent association between the TyG index and MINS through rigorous adjustment for multiple confounding variables overlooked in previous research.

3. This study enhances the applicability of the TyG index-MINS relationship across broader age demographics while addressing a critical gap in previous research.

4. It cannot establish a causal relationship between preoperative TyG and MINS due to the study design.

Introduction

Myocardial injury after noncardiac surgery (MINS) occurs in approximately 3% to 16% of surgical cases [1-3], and is a significant cause of mortality within 30 days postoperatively [1, 4] . The pathophysiology of MINS includes the disruption of atherosclerotic coronary plaques and an imbalance between myocardial oxygen supply and demand. Preoperative coronary angiography is not mandatory for individuals with coronary artery disease (CAD) who do not exhibit apparent myocardial ischemic symptoms, making it challenging to identify high-risk patients preoperatively. Therefore, clinicians need a convenient and practical index for this purpose. Significant risk factors

for CAD include dyslipidaemia and hyperglycaemia. Both obesity [5] and hyperglycaemia [6] have been strongly associated with subclinical myocardial injury (SCeMI), and adverse cardiovascular events (ACEs).

The triglyceride-glucose (TyG) index, derived from triglycerides (TG) and fasting blood glucose (FBG), has been linked to the severity of CAD and ACEs [7-10]. Elevated TyG index levels are associated with increased severity of coronary artery stenosis and a higher number of diseased vessels in patients with acute coronary syndrome (ACS) [11, 12]. The TyG index is a robust predictor of subclinical CAD, even without traditional cardiovascular risk factors (CVRFs) [13]. Furthermore, Kim et al. demonstrated a correlation between higher TyG index levels and the presence of coronary artery calcification plaques in healthy adults [14]. This observation suggests that patients indicated for operation who have a high TyG index and undergo general anaesthesia may possess underlying coronary artery atherosclerosis and a heightened risk of MINS, regardless of CVRFs. Since dyslipidaemia and hyperglycaemia are routinely detectable and modifiable preoperatively, understanding the relationship between MINS and the TyG index is crucial for perioperative management. However, there is limited research on this issue. Therefore, the clinical records from Meizhou People's Hospital were reviewed to investigate whether preoperative TyG levels were associated with MINS. Elevated preoperative TyG index was hypothesised as an independent risk factor for developing MINS.

Methods and materials

Ethics

The Ethical Review Board of Meizhou People's Hospital approved this study, and informed consent was waived (Ethic No. 2023-C-92). This study is registered with the Chinese Clinical Trial Registry (No. ChiCTR2400082834).

Data Source

This study utilised medical records from Meizhou People's Hospital, including the Electronic Medical Record System, Surgical Anaesthesia System, Prescription System, and Laboratory and Examination Systems. The Department of Medical Data and the Department of Medical Administration granted access to these records. Weiming Chen and Fei Liang were responsible for data extraction and cleaning, adhering to the study protocol.

Study Population

Inclusion Criteria: Patients indicated for operation aged ≥40 years, who were administered general anaesthesia and those with troponin measurements recorded within three postoperative days. Exclusion Criteria: (1) Patients <40 years; (2) Patients admitted without FBG and TG measurements; (3) Patients lacking prescription information.

Exposure of interest

The primary exposure was the preoperative TyG index., calculated using the formula: TyG = ln (TG [mg/dL] × FBG [mg/dL] /2) [15, 16]. The conversion formulas used were FBG (mg/dL) = FBG (mmol/L) × 18.0 and TG (mg/dL) = TG (mmol/L) × 88.6. If FBG and TG were measured multiple times preoperatively, the closest measurements to the operation time were utilised.

Variables

The potential variables were categorised into four groups: (1) demographic characteristics, including age, gender, and body mass index (BMI); (2) preoperative comorbidities, including congestive heart failure (CHF), hypertension, CAD, chronic obstructive pulmonary disease (COPD), diabetes, history of stroke, and peripheral vascular disease (PVD); (3) preoperative laboratory results, including haemoglobin (Hb) and estimated glomerular filtration rate (eGFR); (4) surgical information, including the American Society of Anesthesiologists (ASA) Physical Status Classification System, highest intraoperative heart rate to mean arterial pressure (HMR), duration of anaesthesia, and surgical categories.

Outcomes

The outcome of interest was MINS, defined by postoperative troponin levels exceeding the 99th percentile upper reference limit without nonischaemic causes [17, 18].

Statistical Analysis

This study included as many individuals as possible; therefore, no power calculation was conducted. The random forest algorithm was used for multiple imputations of variables with <20% missing data. Variables with >20% missing data were excluded to avoid bias. Patients were categorised into four groups based on the TyG index quartiles. Categorical variables were expressed as proportions. Chi-square tests, Fisher's exact test, were used for unordered categorical variables, and Kruskal-Wallis tests for ordered categorical variables. Continuous variables, expressed as median (interquartile range [IQR]) due to non-normal distribution (per Shapiro–Wilk test), were analysed using the Mann–Whitney U test or Kruskal–Wallis rank sum tests. The diagnostic

performance of TyG for MINS was assessed using receiver operating characteristic (ROC) curves to determine the best cutoff value. Logistic regression analysis identified factors influencing MINS across three models: Model 1: Unadjusted; Model 2: Adjusted for variables with a P-value <0.2 in the univariate analysis, along with clinically relevant variables; Model 3: Adjusted for all predefined variables. Odds ratio (OR) and 95% confidence intervals (CI) were calculated for TyG and the outcome. The linear trend (P trend) was assessed, and a multivariate restricted cubic spline (RCS) model analysed the nonlinear relationship between baseline TyG and MINS. Post-hoc subgroup analyses were stratified by age (≤69 years and >69 years), gender, BMI (<25 and ≥25 kg/m^2), hypertension, and surgical category, with interaction effects tested between subgroups.

A P-value <0.05 indicated statistical significance in two-tailed tests. Based on the open-source R, all statistical analyses were conducted using Stata software (https://www.mstata.com/).

Patient and public involvement

This study did not involve members of the public or patients.

Results

Reporting guideline

This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [19].

Patients characteristics

A total of 889 patients undergoing general anaesthesia were included in the study (Figure 1). Patients were categorised into four groups based on their TyG index (Table 1). The TyG ranges for each group are specified in Table 1. More than half of the patients were men, with a median age of 64 years. The overall median TyG index for all patients was 8.57, and the incidence of MINS was 8.3%. The fourth quartile (Q4) group generally exhibited a higher BMI and a higher prevalence of preoperative hypertension, diabetes, and history of stroke. Patients with a lower TyG index exhibited a lower incidence of MINS than those with a higher TyG index (P = 0.009).

Table 1 Baseline characteristics for patients stratified by TyG index quartiles.

	Overall, N = 889	Q1, N = 223	Q2, N = 222	Q3, N = 222	Q4, N = 222	P
TyG index range	5.03 - 11.33	5.03 - 8.13	8.14 - 8.57	8.58 - 9.02	9.03 - 11.33	/
TyG index quartile	8.57 [8.13, 9.02]	7.85 [7.71, 8.03]	8.37 [8.25, 8.47]	8.75 [8.65, 8.89]	9.44 [9.21, 9.75]	<0.001
Age (years)	64 [55, 72]	64 [55, 73]	64 [55, 72]	65 [58, 73]	60 [54, 69]	<0.001
Sex, man	533 (60.0)	137 (61.4)	148 (66.7)	115 (51.8)	133 (59.9)	0.015
BMI (kg/m^2)	22.1 [20.0, 24.6]	20.4 [18.7, 22.5]	21.9 [19.7, 24.0]	22.8 [20.8, 25.1]	23.5 [21.3, 25.5]	<0.001

Preoperative Lab results						
Hemoglobin (g/L)	129 [112, 140]	124 [109, 137]	128 [112, 138]	130 [116, 140]	131 [114, 145]	0.010
eGFR (mL/min/1.73 m^2)	80 [68, 92]	81 [70, 93]	80 [70, 91]	78 [65, 91]	81 [68, 96]	0.220
Preoperative medical history						
CHF	19 (2.1)	4 (1.8)	4 (1.8)	7 (3.2)	4 (1.8)	0.753
Hypertension	199 (22.4)	27 (12.1)	40 (18.0)	60 (27.0)	72 (32.4)	<0.001
CAD	43 (4.8)	9 (4.0)	7 (3.2)	17 (7.7)	10 (4.5)	0.135
COPD	71 (8.0)	23 (10.3)	21 (9.5)	17 (7.7)	10 (4.5)	0.112
Diabetes	88 (9.9)	4 (1.8)	12 (5.4)	22 (9.9)	50 (22.5)	<0.001
Stroke	50 (5.6)	4 (1.8)	12 (5.4)	11 (5.0)	23 (10.4)	0.001
PVD	58 (6.5)	11 (4.9)	13 (5.9)	18 (8.1)	16 (7.2)	0.538
Preoperative medications						
Rate-controlling	38 (4.3)	9 (4.0)	8 (3.6)	14 (6.3)	7 (3.2)	0.362
Aspirin	26 (2.9)	6 (2.7)	6 (2.7)	7 (3.2)	7 (3.2)	0.983
Statins	81 (9.1)	16 (7.2)	18 (8.1)	25 (11.3)	22 (9.9)	0.442
ASA classification						0.888
I-II	57 (6.4)	12 (5.4)	17 (7.7)	13 (5.9)	15 (6.8)	
III	555 (62.4)	141 (63.2)	139 (62.6)	143 (64.4)	132 (59.5)	
IV-V	277 (31.2)	70 (31.4)	66 (29.7)	66 (29.7)	75 (33.8)	
Duration of anaesthesia (mins)	200 [135, 260]	205 [140, 266]	200 [135, 274]	205 [140, 259]	184 [135, 245]	0.134
The highest intraoperative HMR	1.32 [1.13, 1.62]	1.30 [1.10, 1.54]	1.32 [1.11, 1.64]	1.33 [1.16, 1.65]	1.33 [1.15, 1.65]	0.248
Surgical procedures						0.002
Low-risk	47 (5.3)	12 (5.4)	13 (5.9)	3 (1.4)	19 (8.6)	
Thoracic	201 (22.6)	60 (26.9)	55 (24.8)	53 (23.9)	33 (14.9)	
Non-thoracic major	641 (72.1)	151 (67.7)	154 (69.4)	166 (74.8)	170 (76.6)	
Intraoperative bleeding (ml)	50 [20, 100]	50 [20, 100]	50 [20, 100]	50 [20, 100]	50 [15, 100]	0.405
Outcomes						
MINS within postoperative 3 days	74 (8.3)	10 (4.5)	15 (6.8)	20 (9.0)	29 (13.1)	0.009
Other variables						
TG (mmol/L)	1.19 [0.82, 1.68]	0.70 [0.59, 0.82]	1.04 [0.90, 1.22]	1.46 [1.20, 1.70]	2.16 [1.65, 3.07]	<0.001
Glucose (mmol/L)	5.38 [4.65, 6.83]	4.63 [4.15, 5.30]	5.13 [4.60, 6.04]	5.52 [4.96, 6.63]	7.22 [5.73, 10.25]	<0.001

Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; .BMI: Body Mass Index; eGFR: estimated Glomerular Filtration Rate (CKD-EPI formula); CHF: Congestive Heart Failure; CAD: Coronary Arterial Disease; COPD: Chronic Obstructive Pulmonary Disease; PVD: Peripheral Vascular Disease; ASA: American Society of Anesthesiologist. HMR: heart rate to mean arterial pressure.

Baseline Characteristics of Patients with and without MINS

Supplementary Table S1 details the differences between the MINS and non-MINS groups. The median TyG index was significantly higher in the MINS group than in the non-MINS group (P<0.001). The two groups significantly differed in preoperative eGFR (P = 0.002). Moreover, the MINS group exhibited a significantly higher occurrence of COPD, a history of stroke, and PVD. Preoperative statin use was significantly lower in the non-MINS group (P = 0.027).

ROC Analysis

The TyG index demonstrated higher discriminatory accuracy for MINS than TG and FBG, with an area under the curve (AUC) of 0.624, 0.544, and 0.500, respectively (Supplementary Figure S1). The optimal cutoff value for the TyG index was identified as 8.73 (63.2% specificity and 60.8% sensitivity).

Multivariable Logistic Regression

The continuous TyG index was positively associated with MINS in the crude and adjusted models (Table 2). Neither the Q2 nor the Q3 group exhibited a significantly different risk of MINS than the Q1 group. However, the Q4 group exhibited a substantially increased risk of MINS across all models. A significant linear (P) trend was observed across models 1, 2, and 3.

Table 2 Univariate and multivariate logistic regression for TyG index and MINS

	Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Continuous TyG index per unit	1.72 (1.27 - 2.35)	<0.001	1.54 (1.11 - 2.15)	0.010	1.75 (1.21 - 2.52)	0.003
TyG index quartile group (range)						
Q1 (5.03-8.13)	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2 (8.14-8.57)	1.54 (0.68 - 3.51)	0.301	1.27 (0.55 - 2.98)	0.575	1.44 (0.61 - 3.42)	0.404
Q3 (8.58-9.02)	2.11 (0.96 - 4.61)	0.062	1.90 (0.85 - 4.27)	0.118	2.21 (0.95 - 5.17)	0.066
Q4 (9.03–11.33)	3.20 (1.52 - 6.74)	0.002	2.63 (1.20 - 5.78)	0.016	3.37 (1.46 - 7.81)	0.005
P_{trend}	<0.001		0.006		0.002	

Model 1: Crude; Model 2: Adjusted for age, gender, COPD, PVD, CAD, history of stroke, rate-controlling medications, statins, and eGFR. Model 3: Adjust for age, gender, BMI, preoperative hemoglobin, eGFR, CHF, hypertension, CAD, COPD, diabetes, history of stroke, PVD, rate-controlling medications, aspirin, statins, ASA classification, duration of anesthesia, the highest intraoperative HMR, surgical procedures, intraoperative bleeding. Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; OR: Odds Ratio; CI: Confidence Interval; BMI: body mass index; eGFR: estimated glomerular filtration rate; CHF: congestive heart failure; CAD: coronary arterial disease; COPD: chronic obstructive pulmonary disease; PVD: peripheral vascular disease; ASA: American Society of Anesthesiologist; HMR: heart rate to mean arterial pressure.

RCS Analysis

The RCS analysis revealed a linear increase in the risk of MINS with rising TyG index values (P for nonlinear = 0.059) (Figure 2). The reference point was set at 8.58, consistent with the optimal cutoff value of 8.73 derived from the ROC analysis.

Subgroup analysis

For clinical application, patients were categorised into two groups based on the TyG index (≤8.73

vs. >8.73) to examine subgroup heterogeneity (Figure 3). A TyG index >8.73 was particularly prominent in the following subgroups: patients ≤69 years, female patients, patients with a BMI <25 kg/m², patients without hypertension, and patients undergoing non-thoracic surgery. There was no considerable interaction effect among these subgroups.

Discussion

This study reveals that an elevated preoperative TyG index is independently associated with MINS. Our research provides a novel perspective for risk stratification and management strategies related to MINS. Previous research on the relationship between the preoperative TyG index and postoperative ACEs has been limited.

The TyG index demonstrates greater clinical utility than the homeostasis model assessment of insulin resistance (HOMA-IR) for evaluating insulin resistance (IR) and predicting metabolic disease risk [20]. Its key advantage lies in operational efficiency: HOMA-IR requires fasting insulin measurements, which are often unavailable in low-resource settings, thereby limiting its clinical accessibility. In contrast, the TyG index can be calculated using two routinely measured preoperative parameters - TG and FBG. Recent studies have confirmed a significant positive association between elevated TyG index and several cardiovascular disorders [21], including heart failure [22], ACS and CAD [9, 23], arterial stiffness [24], stroke [25, 26], ACEs [27], and atrial fibrillation [28]. However, the relationship between the preoperative TyG index and MINS remains ambiguous. According to Liu et al., the TyG index is a significant biomarker of SCeMI [29]. Similarly, our study demonstrates a correlation between an elevated preoperative TyG index and a greater risk of MINS, complementing these findings. Compared to FBG and TG, the TyG index demonstrates more robust diagnostic efficacy for MINS, possibly because it more comprehensively reflects the body's metabolic status and arterial disease state. The linear association between the preoperative TyG index and MINS suggests that the TyG index could be used to predict the incidence of MINS in patients indicated for operation. Consistent with previous studies [29, 30], a high TyG index is associated with MINS, even among patients without diabetes and with normal BMI. However, subgroup analysis suggests that the predictive value of the TyG index is weakened in patients with obesity, diabetes, and hypertension. These results may be attributed to differences in population characteristics and disease states, including cardiovascular system damage caused by hyperlipidaemia, diabetes, and hypertension, and the interference of therapeutic drugs (statins,

antidiabetics, and antihypertensive drugs). Complex disease states may limit the predictive ability of the TyG index. In high-risk patients, individualised risk assessment requires a combination of multiple indicators to improve predictive accuracy.

Emerging evidence aligns with our findings, demonstrating that the atherogenic index of plasma (AIP) independently predicts MINS [31]. These investigations synergistically highlight the clinical utility of preoperative metabolic profiling for stratifying postoperative ACEs. Whereas the AIP study focused specifically on the TG-to-high density lipoprotein ratio as a lipid-centric predictor, our TyG index analysis extends this paradigm by evaluating the combined contribution of TG and glucose metabolism to perioperative cardiovascular risk. This complementary approach strengthens the rationale for incorporating multidimensional metabolic assessments into preoperative evaluation of postoperative ACEs. Our findings not only validate the TyG index's predictive capacity but crucially extend its clinical application through population diversification. Our results align with a prior evidence demonstrating the TyG index's association with MINS in geriatric populations (≥65 years) [32]. Notably, our investigation extends beyond this demographic by encompassing younger surgical patients (≥40 years), thereby broadening the validated clinical applicability of the TyG index across age groups underrepresented in existing MINS research. This expanded patient spectrum addresses a critical knowledge gap, as current study predominantly focuses on elderly populations despite the growing prevalence of cardiovascular risk factors in younger adults [1, 17, 33]. Moreover, our study advances the field by establishing a linear dose-response relationship between TyG index values and MINS risk - a finding not previously quantified in earlier investigations. These methodological refinements strengthen the TyG index's utility for preoperative risk stratification in diverse surgical populations.

The association between the TyG index and MINS can be explained through atherosclerosis and metabolic abnormalities. The TyG index is a biomarker of metabolic disorders, and atherosclerotic and cardiovascular diseases [16, 34, 35]. It reflects the degree of CAD and is independently associated with coronary atherosclerosis in healthy adult populations [9, 14]. The TyG index is closely associated with IR [36-39]. IR leads to endothelial dysfunction, increased inflammatory responses, accelerated foam cell formation, and smooth muscle cell proliferation, which promote atherosclerosis and vascular plaque formation [40, 41]. Moreover, IR may reflect platelet reactivity and endothelial-dependent vasodilation [42]. The elevated preoperative TyG

index is associated with hypertension, hyperglycaemia, and hyperlipidaemia, all of which enhance the risk of vascular inflammation, coagulation, and atherosclerosis. These mechanisms contribute to SCeMI [29]. Perioperative hemodynamic changes, inflammatory responses, and oxidative stress may exacerbate pre-existing SCeMi, leading to MINS. Further investigations are needed to elucidate the exact mechanisms associating an elevated TyG index with MINS.

This study highlights the clinical utility of the preoperative TyG index as a simple, cost-effective tool for identifying patients at elevated risk of MINS. Preoperative troponin testing is not routine unless patients have a known history of CAD or exhibit symptoms of myocardial ischemia. The TyG index, more accessible than preoperative troponin, could serve as an alternative screening tool. It is associated with CAD severity, subclinical CAD, SCeMI, and MINS. Clinicians should consider incorporating TyG index screening into preoperative assessments for patients aged ⩾40 years undergoing general anaesthesia, particularly those without overt cardiovascular symptoms. A high TyG index could be helpful for preoperative assessments, including preoperative myocardial status evaluation and guidance for intervention strategies (e.g., glycaemic control and lipid management). For patients with a preoperative TyG index >8.73, heightened vigilance is warranted, including troponin testing, coronary angiography, and medical therapy (such as statins and aspirin), especially for those without a clear CAD history. Our findings suggest that preoperative TyG index evaluation could refine perioperative risk stratification and guide targeted interventions to mitigate MINS-related complications. Randomised controlled trials (RCTs) are necessary to verify the optimal strategies based on the preoperative TyG index evaluation.

Limitations

This study has several limitations. First, residual confounding factors may have introduced bias, such as excluding patients <40 years old and those lacking preoperative FBG and TG measurements. Second, preoperative troponin screening was not performed for all patients indicated for surgery, potentially missing those with preoperative myocardial injury and introducing selection bias. This study limited its troponin measurements to patients with myocardial ischemia symptoms. Since asymptomatic myocardial injury is prevalent among postoperative patients, our study may not fully capture the potential association between the preoperative TyG index and asymptomatic myocardial injury. Current guidelines recommend troponin measurements (Class I recommendation) for patients who develop myocardial ischemia symptoms following non-cardiac surgeries. For those at

high risk but without postoperative ischemic signs, a Class IIb recommendation is given [43]. The high rate of missing HbA1c data led to its exclusion from the primary analysis. However, multivariate logistic regression analysis on the subset of data containing HbA1c yielded results consistent with the primary analysis (Supplementary Table S2). Third, our study focused solely on the association between baseline TyG index and MINS. Future RCTs are essential to determine the impact of variations in the TyG index on MINS prevention, mainly through preoperative interventions targeting lipid and glucose levels.

Conclusion

An elevated preoperative TyG index is positively associated with a higher incidence of MINS. It can be used to assess the risk of MINS preoperatively. Further research is required to determine if controlling and monitoring the TyG index can reduce postoperative ACEs.

Legends

Figure 1 Flowchart of the study population

Fig.1 Flow diagram illustrating the inclusion and exclusion of cases. TG: triglyceride.

Figure 2 RCS of TyG and MINS

Fig.2 The central heavy blue line represents the adjusted odds ratio, with shaded bands indicating the 95% CI. The horizontal dotted line represents an odds ratio of 1.0. The solid blue dot indicates the reference point for the TyG index (8.58). The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. RCS: restricted cubic spline; TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

Figure 3 Post-hoc subgroup analysis

Fig.3 Forest plots depicting the relationship between the TyG index (≤8.73 and >8.73) and MINS. The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; OR: odds ratio; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

Abbreviations

MINS: Myocardial injury after noncardiac surgery

CAD: Coronary artery disease

SCeMI: Subclinical myocardial injury

ACEs: Adverse cardiovascular events

TG: Triglycerides

FBG: Fasting blood glucose

ACS: Acute Coronary Syndrome

TyG index: Triglyceride-glucose index

cVRFs: Traditional cardiovascular risk factors

BMI: Body Mass Index

CAD: Coronary artery disease

CHF: Congestive heart failure

COPD: Chronic obstructive pulmonary disease

PVD: Peripheral vascular disease

Hb: Hemoglobin

eGFR: estimated Glomerular Filtration Rate

ASA: American Society of Anesthesiologists

HMR: heart rate to mean arterial pressure ratio

MINS: Myocardial injury after noncardiac surgery

ROC: Receiver operating characteristic

OR: Odds Ratio

CI: Confidence Interval

RCS: Restricted cubic spline

HOMA-IR: Homeostasis model assessment of insulin resistance

IR: insulin resistance

AIP: Atherogenic index of plasma

RCTs: randomized controlled trials

Ethics

The Ethical Review Board of Meizhou People's Hospital reviewed the study protocol and approved this study, and informed consent was not required (Ethic No. 2023-C-92). We have also registered this study at the Chinese Clinical Trial Registry (No. ChiCTR2400082834).

Data availability statement

The corresponding author can grant data access to this study upon request.

Consent for publication

All authors revised the manuscript and approved the submission.

Competing interest

The authors have no conflicts of interest to declare.

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Patient and public involvement

This study did not involve members of the public or patients.

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Authors' contributions

Yuanjun Zhou: study design, data collection and examination, data analysis, and manuscript drafting, manuscript revision; Weiming Chen and Fei Liang: data examination and analysis, manuscript drafting, manuscript revision; Liping Zhong: data examination and data analysis; Yilin Liao: data examination and analysis and the supervision of the study process, manuscript revision; Yuting Zhong (guarantor): study design, data collection, and examination, data analysis, manuscript drafting, manuscript revision and supervision of the study process.

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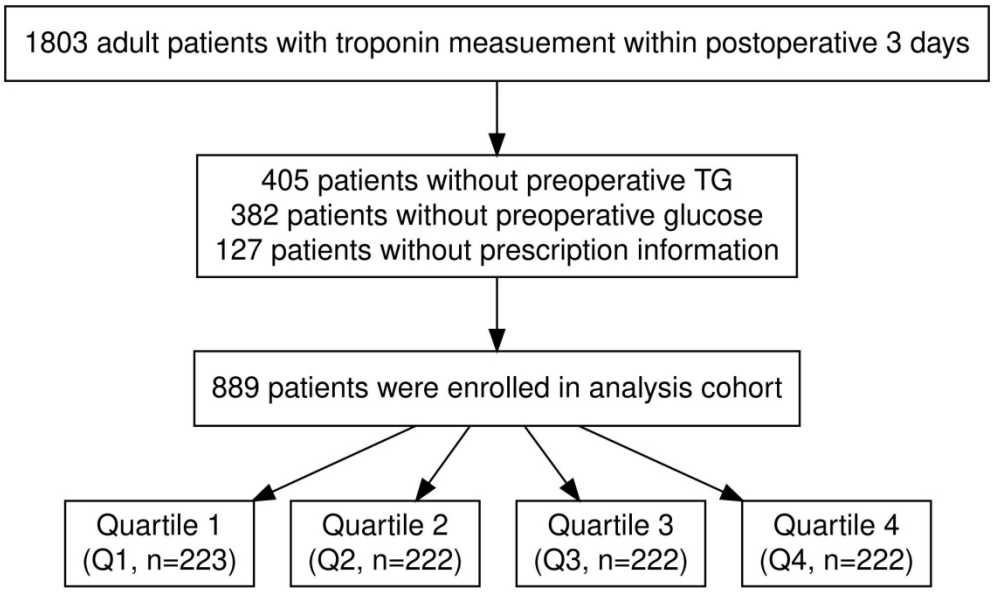

Figure 1 Flowchart of the study population
Fig.1 Flow diagram illustrating the inclusion and exclusion of cases. TG: triglyceride.

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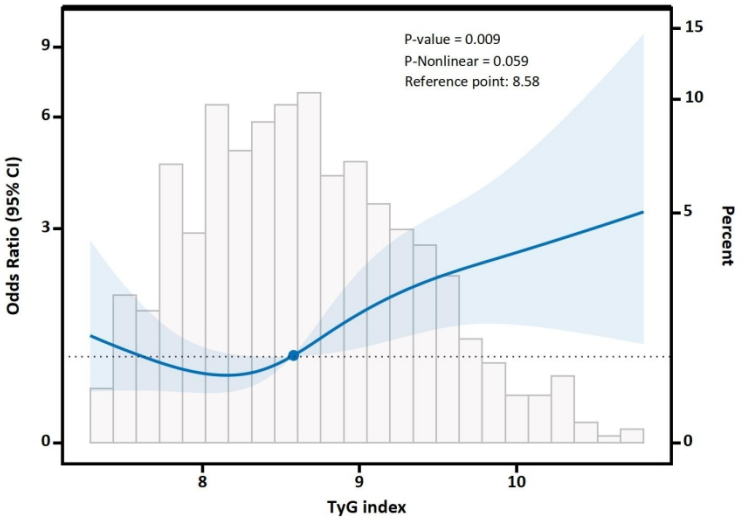

Figure 2 RCS of TyG and MINS

Fig.2 The central heavy blue line represents the adjusted odds ratio, with shaded bands indicating the 95% CI. The horizontal dotted line represents an odds ratio of 1.0. The solid blue dot indicates the reference point for the TyG index (8.58). The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. RCS: restricted cubic spline; TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

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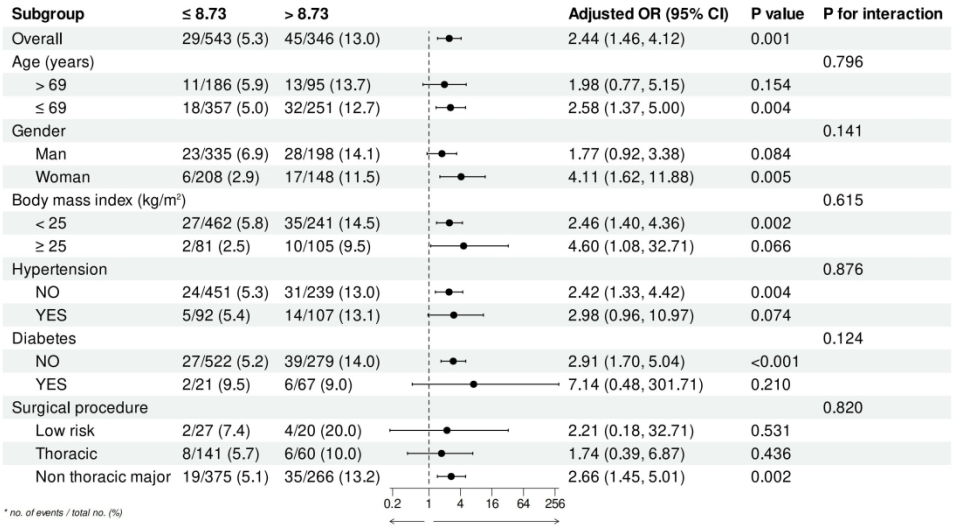


Figure 3 Post-hoc subgroup analysis

Fig.3 Forest plots depicting the relationship between the TyG index (≤8.73 and >8.73) and MINS. The ORs were adjusted for age, gender, CAD, COPD, stroke, PVD, rate-controlling medications, statins, and eGFR. TyG index: triglyceride-glucose index; MINS: myocardial injury after noncardiac surgery; OR: odds ratio; CI: confidence interval; CAD: Coronary artery disease; COPD: Chronic obstructive pulmonary disease; PVD: Peripheral vascular disease; eGFR: Estimated glomerular filtration rate.

268x152mm (300 x 300 DPI)

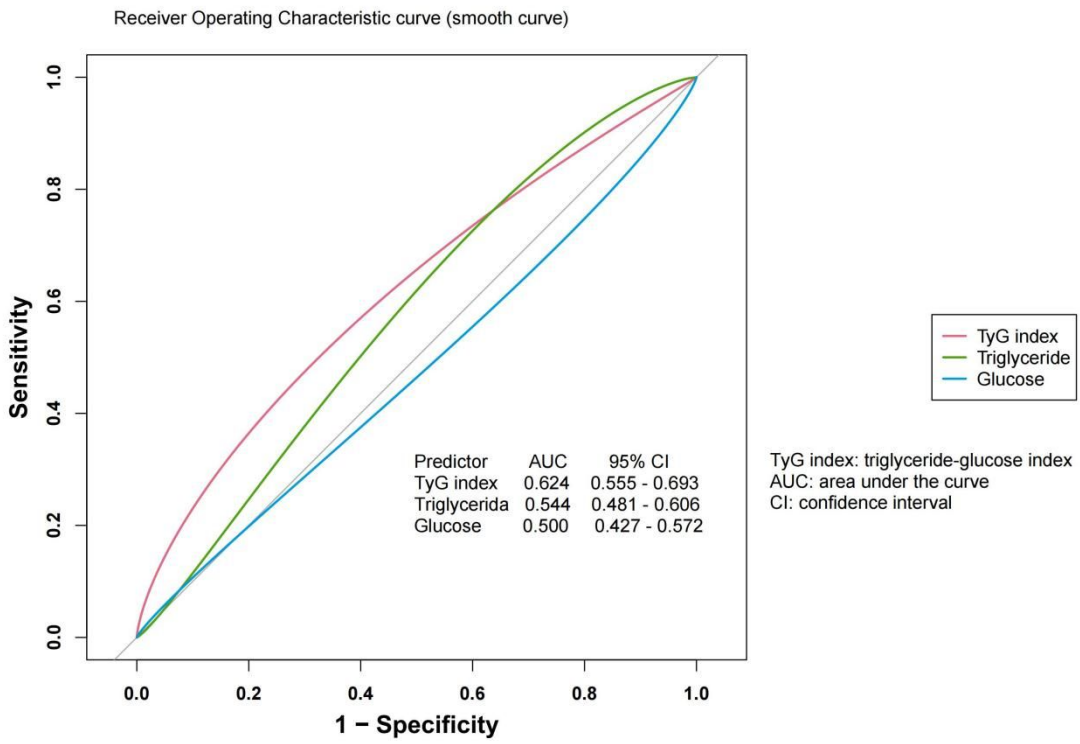
Supplementary materials

Supplementary Table S1 Baseline characteristics for patients stratified by MINS and non-MINS.

		MINS		
	Overall, N = 889	NO, N = 815	YES, N = 74	P
TyG index quartile	8.57 [8.13, 9.02]	8.54 [8.12, 9.00]	8.84 [8.41, 9.42]	<0.001
Age (years)	64 [55, 72]	64 [55, 72]	64 [58, 72]	0.215
Sex, male	533 (60.0)	482 (59.1)	51 (68.9)	0.100
BMI (kg/m^2)	22.1 [20.0, 24.6]	22.1 [20.0, 24.6]	22.8 [20.7, 24.4]	0.391
Preoperative Lab results				
Hemoglobin (g/L)	129 [112, 140]	129 [112, 140]	127 [111, 139]	0.440
eGFR (mL/min/1.73 m^2)	80 [68, 92]	81 [70, 92]	71 [54, 91]	0.002
Preoperative medical history				
CHF	19 (2.1)	16 (2.0)	3 (4.1)	0.205
Hypertension	199 (22.4)	180 (22.1)	19 (25.7)	0.478
CAD	43 (4.8)	37 (4.5)	6 (8.1)	0.161
COPD	71 (8.0)	60 (7.4)	11 (14.9)	0.023
Diabetes	88 (9.9)	80 (9.8)	8 (10.8)	0.784
Stroke	50 (5.6)	38 (4.7)	12 (16.2)	<0.001
PVD	58 (6.5)	46 (5.6)	12 (16.2)	0.002
Preoperative medications				
Rate-controlling	38 (4.3)	38 (4.7)	0 (0.0)	0.066
Aspirin	26 (2.9)	25 (3.1)	1 (1.4)	0.716
Heparin	164 (18.4)	148 (18.2)	16 (21.6)	0.462
Statins	81 (9.1)	69 (8.5)	12 (16.2)	0.027
ASA classification				0.717
I-II	57 (6.4)	54 (6.6)	3 (4.1)	
III	555 (62.4)	509 (62.5)	46 (62.2)	
IV-V	277 (31.2)	252 (30.9)	25 (33.8)	
Duration of anesthesia (mins)	200 [135, 260]	200 [135, 260]	185 [140, 260]	0.839
The highest intraoperative HMR	1.32 [1.13, 1.62]	1.32 [1.13, 1.61]	1.40 [1.10, 1.67]	0.497
Surgical procedures				0.390
Low-risk	47 (5.3)	41 (5.0)	6 (8.1)	
Thoracic	201 (22.6)	187 (22.9)	14 (18.9)	
Non-thoracic major	641 (72.1)	587 (72.0)	54 (73.0)	
Intraoperative bleeding (ml)	50 [20, 100]	50 [20, 100]	30 [20, 80]	0.402
Other variables				
TG (mg/dl)	1.19 [0.82, 1.68]	1.19 [0.82, 1.70]	1.10 [0.82, 1.55]	0.212
Glucose (mg/dl)	5.38 [4.65, 6.83]	5.37 [4.66, 6.82]	5.53 [4.56, 6.83]	0.997

Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; .BMI: Body Mass Index; eGFR: estimated Glomerular Filtration Rate (CKD-EPI formula); CHF: Congestive Heart Failure; CAD: Coronary Arterial Disease; COPD: Chronic Obstructive Pulmonary Disease; PVD: Peripheral Vascular Disease; ASA: American Society of Anesthesiologist. HMR: heart rate to mean arterial pressure.

Supplementary Figure S1



Supplementary Table S2 Univariate and multivariate logistic regression for TyG index and MINS

	Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
Continuous TyG index per unit	2.993(1.732-5.172)	<0.001	3.527(1.797-6.922)	<0.001	4.041(1.900-8.596)	<0.001

Model 1: Crude; Model 2: Adjusted for age, gender, COPD, PVD, CAD, history of stroke, rate-controlling medications, statins, eGFR, HbA1c. Model 3: Adjust for age, gender, BMI, preoperative hemoglobin, eGFR, CHF, hypertension, CAD, COPD, diabetes, history of stroke, PVD, rate-controlling medications, aspirin, statins, ASA classification, duration of anesthesia, the highest intraoperative HMR, surgical procedures, intraoperative bleeding. Abbreviations TyG index: triglyceride-glucose index; MINS: Myocardial Injury after Noncardiac Surgery; OR: Odds Ratio; CI: Confidence Interval; BMI: body mass index; eGFR: estimated glomerular filtration rate; CHF: congestive heart failure; CAD: coronary arterial disease; COPD: chronic obstructive pulmonary disease; PVD: peripheral vascular disease; ASA: American Society of Anesthesiologist; HMR: heart rate to mean arterial pressure.