Cardiovascular Diabetology

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Triglyceride-glucose index correlates with the occurrence and prognosis of acute myocardial infarction complicated by cardiogenic shock: data from two large cohorts

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Abstract

Background Triglyceride-glucose (TyG) index, a dependable indicator of insulin resistance, has been identified as a valid marker regarding multiple cardiovascular diseases. Nevertheless, the correlation of TyG index with acute myocardial infarction complicated by cardiogenic shock (AMICS) remains uncertain. Our study aims for elucidating this relationship by comprehensively analyzing two large-scale cohorts.

Methods Utilizing records from the eICU Collaborative Research Database and the Medical Information Mart for Intensive Care IV, the link between TyG and the incidence and prognosis of AMICS was assessed multicentrally and retrospectively by logistic and correlation models, as well as restricted cubic spline (RCS). Propensity score matching (PSM), inverse probability of treatment weighting (IPTW), and overlap weighting (OW) were employed to balance the potential confounders. Subgroup analyses were performed according to potential modifiers.

Results Overall, 5208 AMI patients, consisting of 375 developing CS were finally included. The TyG index exhibited an apparently higher level in AMI populations developing CS than in those who did not experienced CS [9.2 (8.8–9.7) vs. 9.0 (8.5–9.5)], with a moderate discrimination ability to recognize AMICS from the general AMI (AUC: 0.604). Logistic analyses showed that the TyG index was significantly correlated with in-hospital and ICU mortality. RCS analysis demonstrated a linear link between elevated TyG and increased risks regarding in-hospital and ICU mortality in the AMICS population. An increased mortality risk remains evident in PSM-, OW- and IPTW-adjusted populations with higher TyG index who have undergone CS. Correlation analyses demonstrated an apparent link between TyG index and APS score. Subgroup analyses presented a stable link between elevated TyG and mortality particularly in older age, females, those who are overweight or hypertensive, as well as those without diabetes.

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Conclusions Elevated TyG index was related to the incidence of CS following AMI and higher mortality risks in the population with AMICS. Our findings pointed a previously undisclosed role of TyG index in regard to AMICS that still requires further validation.

Keywords Triglyceride-glucose index, Insulin resistance, Acute myocardial infarction, Cardiogenic shock

Introduction

Cardiogenic shock (CS), characterized by severely diminished cardiac output, is a relatively rare but typically fatal condition associated with high global mortality [1]. Acute myocardial infarction (AMI) continues to be the leading cause regarding CS, and CS occurs in 3–13% of cases following AMI [2–4]. Once CS develops, mortality rates sharply increase from less than 4% in the general AMI population to approximately 50%, despite advancements in medical care over the past decades for acute myocardial infarction complicated by cardiogenic shock (AMICS) [5–7]. Even worse, forecasting the occurrence of CS following AMI remains challenging.

As a gravely deteriorating stage of AMI, AMICS may share certain common risk elements seen in atherosclerosis, including diabetes mellitus (DM), hyperlipemia, as well regarding obesity. Among sixty subjects diagnosed with acute coronary syndrome, CS was found to be more prevalent among those with higher admission insulin resistance (IR) index [8]. Individuals with ST elevation myocardial infarction are at a higher risk of developing CS if they present with metabolic syndrome [9]. Stress hyperglycemia upon admission is frequently observed in patients who experience AMICS, and it is correlated with adverse survival outcomes [10, 11]. Moreover, both diabetes and overweight/obesity have been identified as independent risk factors for mortality events in those undergoing AMICS [12–14]. Collectively, all existing evidence implies that disturbances in glucolipid metabolism may participate in the pathogenesis of CS following AMI, indicating a potential undisclosed correlation of IR with the occurrence and outcomes regarding AMICS.

The triglyceride-glucose (TyG) index, recognized as an efficient and convenient indicator for IR, has garnered increasing recognition in recent years for its diagnostic value in cardiovascular disorders [15–17]. Importantly, apparent correlations have been reported between elevated TyG levels and unfavorable outcomes in various cardiovascular conditions such as cardiac arrest (CA) [18], AMI [19], heart failure [20], and atrial fibrillation [21]; and simultaneously, Abuduaini et al. have explored a positive link between the TyG index and CS risks among populations having ischemic cardiomyopathy [22]. Overall, these findings highlight that TyG might hold promise in predicting the occurrence and prognosis of CS after AMI; however, conclusive evidence is currently lacking.

Herein, we sought to evaluate the association of the TyG index with AMICS, aiming for accurately identifying or timely intervening a new indicator associated with adverse prognosis from energy metabolism perspective.

Methods

Study design and population

We conducted a multicentre, observational, retrospective study to evaluate the correlation of the TyG index with AMICS, comprehensively utilizing 788 records from the Medical Information Mart for Intensive Care IV (MIMIC-IV) database (version 2.2) and 4420 records from the eICU Collaborative Research Database (eICU-CRD). The diagnoses of AMI and CS were determined using the International Classification of Diseases, 9th and 10th Revision. Patients under the age of 18 or with insufficient data on FBG or TG were excluded from analysis, while only the initial in-hospital record was assessed for those with multiple admissions.

The current study consisted of two main parts. In the initial part, we evaluated the disparity in TyG levels between AMI patients with and without CS occurrence. Subsequently, we further stratified the AMICS population according to TyG levels or survival outcomes for further analyses.

Data source

MIMIC-IV (version 2.2), a widely used single-center database, containing high-quality and comprehensive medical records on patients admitted to the ICUs at Beth Israel Deaconess Medical Center from 2008 to 2019. The project received approval from the institutional review boards of Massachusetts Institute of Technology and Beth Israel Deaconess Medical Center, with an exemption from informed consent. One author (HRL) was responsible for extracting data.

eICU-CRD, a multicenter database encompassing over 200,000 admissions regarding ICU populations in the United States at 208 hospitals from 2014 to 2015. This database is publicly accessible, normatively administered, and of high quality. One author (HRL) was responsible for extracting data.

Data extraction

Data extracted were listed as below: (a) demographic data, such as age, gender, and body mass index (BMI); (b) baseline vital signs, such as heart rate (HR), respiratory rate (RR), temperature, mean arterial pressure (MAP), and saturation of peripheral oxygen (SpO2); (c) comorbidities, such as hypertension, diabetes mellitus (DM),

acute renal failure (ARF), chronic heart failure, hepatitis, stroke, COPD, cardiac arrest (CA), and CKD; (d) baseline laboratory data, including white blood cell (WBC), red blood cell (RBC), platelet, hemoglobin (Hb), aspartate aminotransferase (AST), alanine aminotransferase (ALT), blood urea nitrogen (BUN), creatinine, creatine kinase-myocardial band (CK-MB), lactate (LAC), N-terminal pro-brain natriuretic peptide (NT-pro BNP), fasting blood glucose (FBG), total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), international normalized ratio, sodium, potassium, and acute physiology score (APS); (e) in-hospital therapy data, including the use of coronary artery bypass grafting (CABG), the use of percutaneous coronary intervention (PCI), invasive mechanical ventilation (IMV), epinephrine, and norepinephrine. No patient identifying information was showed. BMI was computed via: weight (kg) / [height $(m)^2$]. TyG index was computed via: ln [fasting TG (mg/dl) * FBG (mg/dl)/2] [23].

Endpoints

The primary outcomes included in-hospital and ICU mortality. Other data, such as the length of stay in hospital (LOS-H) and the length of stay in ICU (LOS-ICU) were reported as secondary outcomes.

Statistical analysis

Statistical analyses were conducted through SPSS (version 23.0, USA), R software (version 3.5.1, Austria) and Graph prism (version 9.0, USA). Continuous variable was showed as median (25th-75th percentiles) and examined using Mann-Whitney test. Categorical variable was showed as absolute number (percentage) and examined using chi-square test. Lacking values were imputed using multiple imputations. Statistical significance was recognized when two-tailed $P<0.05$.

For logistic analyses, univariate and multivariate models were set to assess the predictive role of TyG for mortality. And the TyG index was evaluated using two different patterns, respectively, as: (a) categorical variables; and (b) continuous variables. Confounders were selected based on statistical difference regarding baseline characteristics and clinical importance. Moreover, the RCS analyses were utilized to ascertain the non-linear correlation of TyG levels with mortalities.

Following stratifying the AMICS populations based on TyG index levels (<9.22 and >9.22), a 1:1 matching propensity score matching (PSM) analysis was performed, resulting in 106 individuals in each group. In addition, the inverse probability of treatment weighting (IPTW) and the overlap weighting (OW) analyses were utilized to achieve a standardized population, thereby mitigating potential biases. Correlation analysis was utilized to assess the relationship of TyG with continuous indicators, including LOS-H, LOS-ICU, LDL-C, etc.

Further subgroup analyses were conducted based on gender, age, BMI, CA, DM, and hypertension. Logistic regression model employed in subgroup analyses, incorporating all variables from Model 3 except the one utilized for stratification.

Results

Elevated TyG index is presented in AMI patients who developed CS

In total, 5208 critically ill patients (mean age: 64.0 years; 65.4% men) diagnosed with AMI were finally enrolled, consisting of 788 individuals from the MIMIC cohort and 4420 from the eICU cohort (Fig. 1). Among, 375 occurred CS. There are several differences regarding the general characteristics between AMI populations with and without CS, as outlined in Table 1.

Individuals occurring with CS presented significantly higher TyG index in comparison to those without CS [9.2 (8.8–9.7) vs. 9.0 (8.5–9.5)]. Based on this finding, we additionally evaluated the correlation of TyG levels with the risk of developing CS among populations with AMI through logistic regression analyses. Both univariate and multivariate logistic analyses suggested a significant predictive value of TyG index for AMI individuals developing CS (OR_{model1}: 1.606, OR_{model2}: 1.741, OR_{model3}: 1.231) (Table 2). Moreover, the ROC curve displayed superior performance of TyG index in recognizing CS occurrences from the overall AMI population (AUC: 0.604, 95% CI: 0.574–0.633) compared to age, gender, BMI, CK-MB, NT-pro BNP, MAP, hypertension, LDL-C, HDL-C and TC (Figs. 2, 3 and Table S1).

On the whole, these findings validated the correlation of elevated TyG with the hazard of AMICS, suggesting that the TyG index might serve as a valuable predictor for the development of CS in patients with AMI.

Baseline characteristics and clinical outcomes of populations with AMICS

Additionally, as showed in Table S2 and S3, among the 375 individuals who occurred AMICS, a sum of 101 patients died at hospital discharge and 85 died at ICU discharge. Meanwhile, our data demonstrated that non-survivors exhibited apparently higher TyG levels than survivors, regardless of during their hospital stay [9.4 (8.9–10.1) vs. 9.2 (8.7–9.6)] or in the ICU [9.4 (8.8–10.0) vs. 9.2 (8.7–9.6)]. Participants were further separated into three groups according to TyG tertiles, there are several differences regarding the baseline characteristics among those three groups (Table 3).

As shown in Table 4, in comparison to those with lower TyG, patients with higher TyG levels exhibited apparently higher in-hospital and ICU mortality rates,

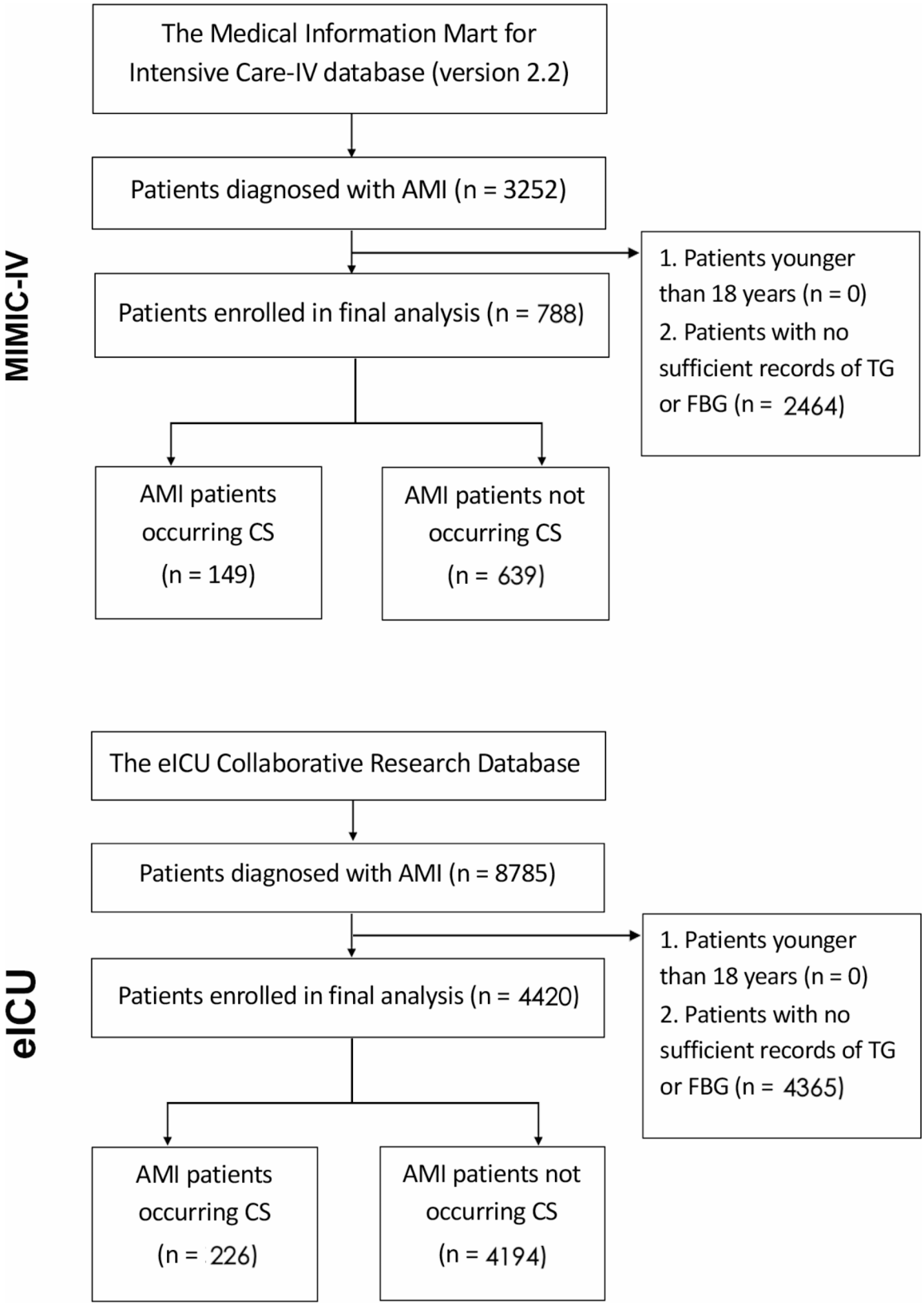

Fig. 1 Flow diagram of patient selection from MIMIC-IV and eICU databases. AMI, acute myocardial infarction; CS, cardiogenic shock; TG, triglyceride; FBG, fasting blood glucose

Table 1 Baseline characteristics between AMI patients with and without CS

Characteristics	All AMI patients (*n* = 5208)	AMI patients without CS (*n* = 4833)	AMI patients with CS (*n* = 375)	*P* value
Demographic data				
Age, y	64.0 (55.0–74.0)	64.0 (55.0–74.0)	67.0 (58.0–76.0)	0.002
Sex, n (%)				
Male	3407 (65.4)	3166 (65.5)	241 (64.3)	
Female	1801 (34.6)	1667 (34.5)	134 (35.7)	
BMI, kg/m^2	28.7 (25.1–33.0)	28.7 (25.1–33.0)	28.2 (25.0–33.2)	0.631
Vital signs				
Heart rate, bpm	77.0 (68.1–87.5)	76.2 (67.7–86.5)	86.4 (77.6–98.5)	< 0.001
MAP, mmHg	83.5 (75.9–92.1)	84.0 (76.4–92.7)	76.2 (70.6–84.0)	< 0.001
RR, bpm	18.5 (16.5–21.0)	18.4 (16.5-20.8)	19.9 (17.3–23.2)	< 0.001
Temperature, ℃	36.7 (36.6–36.9)	36.7 (36.6-36.9)	36.8 (36.5–37.1)	0.022
SpO_2, %	97.0 (95.7–98.2)	97.0 (95.7-98.2)	97.1 (95.4–98.5)	0.870
Comorbidities, n (%)				
Hypertension	1091 (21.0)	996 (20.6)	95 (25.3)	0.030
Diabetes mellitus	293 (5.6)	240 (5.0)	53 (14.1)	< 0.001
Chronic heart failure	365 (7.0)	251 (5.2)	114 (30.4)	< 0.001
Acute renal failure	703 (13.5)	527 (10.9)	176 (46.9)	< 0.001
Hepatitis	33 (0.6)	28 (0.6)	5 (1.3)	0.076
Stroke	315 (6.1)	289 (6.0)	26 (6.9)	0.456
COPD	277 (5.3)	245 (5.1)	32 (8.5)	0.004
Cardiac arrest	371 (7.1)	269 (5.6)	102 (27.2)	< 0.001
Chronic kidney disease	385 (7.4)	331 (6.9)	54 (14.4)	< 0.001
Laboratory data				
WBC, M/mcl	11.0 (8.6–13.9)	10.8 (8.6–13.5)	14.2 (11.0–18.1)	< 0.001
RBC, K/mcl	4.3 (3.8–4.8)	4.4 (3.9–4.8)	4.1 (3.6–4.6)	< 0.001
PLT, K/mcl	213.6 (174.0–260.0)	214.8 (175.0–260.5)	201.4 (166.6–251.8)	0.009
Hb, g/dL	13.1 (11.5–14.4)	13.2 (11.6–14.4)	12.5 (10.7–13.8)	< 0.001
ALT	33.0 (21.6–55.0)	32.0 (21.0–51.0)	70.3 (36.1–149.8)	< 0.001
AST	55.5 (28.0–138.0)	51.0 (27.0–122.0)	181.5 (70.0–498.2)	< 0.001
BUN	17.0 (13.0–24.0)	17.0 (13.0–23.5)	22.0 (16.5–33.7)	< 0.001
Creatinine	1.0 (0.8–1.3)	1.0 (0.8–1.3)	1.3 (1.0–1.9)	< 0.001
CK-MB	40.0 (10.0–118.6)	38.1 (9.5–111.2)	79.1 (17.3–232.5)	< 0.001
LAC	2.0 (1.4–3.3)	1.9 (1.3–3.0)	2.6 (1.6–4.6)	< 0.001
NT-pro BNP	560.5 (166.9–1795.3)	532.2 (160.0–1697.0)	1108.0 (362.5–6038.5)	< 0.001
FBG	127.0 (106.0–168.0	125.0 (105.0–163.0)	165.0 (130.0–248.0)	< 0.001
TG	117.0 (84.0–172.0)	117.0 (84.0–173.0)	113.0 (84.0–158.0)	0.495
TyG index	9.0 (8.6–9.5)	9.0 (8.5-9.5)	9.2 (8.8–9.7)	< 0.001
TC	160.0 (132.0–190.0)	161.0 (132.0–191.0)	144.5 (119.0–170.3)	< 0.001
HDL-C	39.0 (32.0–47.5)	39.0 (32.0–47.0)	40.0 (31.0–48.0)	0.769
LDL-C	92.0 (67.7–120.0)	94.0 (68.0–121.0)	80.0 (58.5–102.5)	< 0.001
INR	1.1 (1.0-1.2)	1.1 (1.0–1.2)	1.2 (1.1–1.4)	< 0.001
Sodium	138.0 (136.0–140.0)	138.0 (136.0–140.0)	138.5 (136.0–140.5)	0.019
Potassium	4.1 (3.8–4.4)	4.1 (3.8–4.3)	4.1 (3.8–4.5)	0.049
APS score	31.0 (22.0–44.0	30.0 (22.0–41.0)	51.0 (37.0–77.0)	< 0.001
Therapy data, n (%)				
CABG	118 (2.3)	88 (1.8)	30 (8.0)	< 0.001
PCI	1686 (32.4)	1571 (32.5)	115 (30.7)	0.463
IMV	485 (9.3)	339 (7.0)	146 (38.9)	< 0.001
Epinephrine	51 (1.0)	22 (0.5)	29 (7.7)	< 0.001
Norepinephrine	442 (8.5)	293 (6.1)	149 (39.7)	< 0.001

Table 2 Logistic regression analyses regarding the association between the TyG index and the occurrence of CS in AMI populations

TyG index	OR	95% CI	*P*-value
Model 1	1.606	1.405–1.836	< 0.001
Model 2	1.741	1.514–2.001	< 0.001
Model 3	1.231	1.029–1.472	0.023

TyG index, triglyceride-glucose index; OR, odds ratio; CI, confidence interval

Model 1: unadjusted

Model 2: Adjusted for age, gender, and body mass index

Model 3: Adjusted for age, gender, body mass index, heart rate, mean arterial pressure, respiratory rate, temperature, hypertension, diabetes mellitus, chronic heart failure, acute renal failure, chronic obstructive pulmonary disease, cardiac arrest, chronic kidney disease, white blood cell, red blood cell, platelet, hemoglobin, alanine transaminase, aspartate transaminase, blood urea nitrogen, creatinine, creatine kinase-myocardial band, lactate, N-terminal pro-brain natriuretic peptide, total cholesterol, low density lipoprotein cholesterol, international normalized ratio, sodium, potassium, coronary artery bypass grafting, use of invasive mechanical ventilation, epinephrine, and norepinephrine

as well regarding longer LOS-H. However, no significant difference was observed regarding LOS-ICU among those three groups. Them, we further performed trend analyses (Fig. 2), and we found an increased trend for in-hospital (*P* for trend = 0.002) and ICU mortality (*P* for trend = 0.011) with elevated TyG tertiles. An increasing trend was also observed for LOS-ICU (*P* for trend = 0.007), but not with respect to LOS-H.

On the whole, these findings suggested that elevated TyG has the potential to be associated with prognoses of patients suffering from AMICS

Elevated TyG index is correlated with higher mortality in the AMICS population

To ulteriorly assess the correlation of TyG index with survival endpoints, logistic regression analyses were employed (Table 5). Univariate logistic regression analyses indicated an apparent association between mortality and the TyG index, with an OR of 1.482 for in-hospital mortality and an OR of 1.426 for ICU mortality, per unit increase in the TyG index. And compared to those in the lowest tertile, the risks of in-hospital and ICU mortality were 2.263 and 1.980 times higher for individuals in the highest tertile, respectively. These associations remained robust after controlling for confounders. In the full-adjusted Model 3, for per unit increase in the TyG index, risks of in-hospital and ICU mortality increased by 58.9% and 41.7% (OR: 1.589 and 1.417, respectively). Compared to the lowest tertile, the highest tertile was associated with a 2.544-fold increase in in-hospital mortality and a 1.978-fold increase in ICU mortality. In addition, a significant tendency of increasing risk was observed for mortality with elevated TyG tertiles (all *P* for trend < 0.05).

Besides, we conducted Pearson's and Spearman's analyses to demonstrate the relationship of TyG index with specific factors including LOS-H, LOS-ICU, HDL-C, LDL-C, TC and APS score, and the results indicated significant associations of TyG levels with the aforementioned indicators (Table S4). Further multiple linear analyses were conducted, and the findings exhibited that the TyG was apparently linked to the levels of APS scores (beta: 0.136) but not LOS-H nor LOS-ICU, after adjusting for confounders (Table S5).

On the whole, these findings indicated that elevated TyG index was strongly correlated with poor prognosis for populations with AMICS, particularly in regard to in-hospital and ICU mortality.

AMI populations with higher TyG index exhibited higher risks of developing CS

The results of RCS analyses depicted in Fig. 4 demonstrated a linear correlation of elevated TyG with increased in-hospital (P for nonlinear: 0.420) and ICU mortality (P for nonlinear: 0.897) hazards, after adjusting for age, gender, and BMI. Then, we grouped this cohort in accordance with TyG cut-off point of 9.22, and there are several differences regarding characteristics between these two groups (Table S6). To mitigate potential confounders, we further performed PSM, OW and IPTW analyses, and the baseline characteristics have been listed in Table S7 and S8.

As shown in Fig. 5 and Table S9, in the original cohort, in-hospital and ICU death occurred in 101 (26.9%) and 85 (22.7%) populations, respectively. In comparison to the lower TyG, patients with higher TyG exhibited higher in-hospital (31.9% vs. 21.9%) and ICU (27.1% vs. 18.2%) mortality rates, as well regarding longer LOS-ICU [5.4 (2.9–12.1) days vs. 4.2 (2.1–8.4) days] but not LOS-H in the unadjusted cohort. An elevated mortality for those with higher TyG index was likewise observed in PSM-, OW- and IPTW-adjusted populations (all $P < 0.05$), while clinical outcomes in terms of the LOS-H and LOS-ICU were not quite consistent. IPTW-matched cohort demonstrated statistically shorter LOS-H [16.6 (8.2–36.3) days vs. 27.8 (12.9–44.7) days] and LOS-ICU [9.2 (5.2–22.6) days vs. 13.9 (5.5–25.3) days], while no significant differences were noted post-PSM. Meanwhile, after OW-adjusting, only a significantly longer LOS-ICU was observed for those with higher TyG index [9.2 (5.2–22.6) days vs. 7.3 (3.6–15.8) days].

On the whole, these findings indicated that an elevated TyG was stably correlated with increased mortality for patients with AMICS, even after various statistical adjustments.

Subgroup analysis

Further estimation of the predictive role of TyG index regarding mortality outcomes was performed in various subclasses of our population, according to age, gender, BMI, hypertension, DM, and CA (Fig. 6). We identified

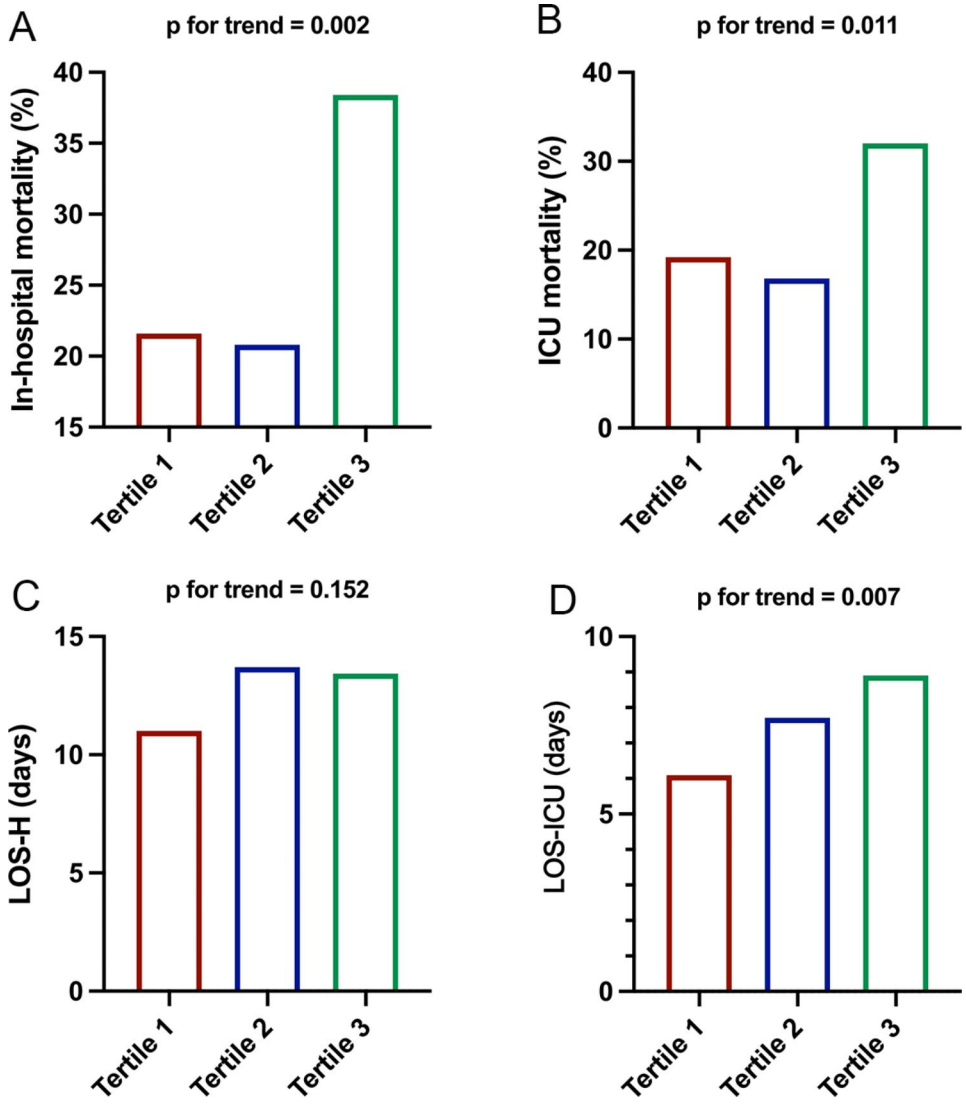

Fig. 2 Endpoints stratified by tertiles of TyG index in the AMICS population. **A** in-hospital mortality; **B** ICU mortality; **C** LOS-H; **D** LOS-ICU. ICU, intensive unit care; LOS-H, length of stay in hospital; LOS-ICU, length of stay in intensive unit care

that the TyG index was consistently related to increased risks of both in-hospital and ICU mortality among elder, female, overweight, hypertensive populations, also those without DM. Notably, the TyG index also exhibited an apparent correlation with in-hospital mortality in younger, normotensive patients, and those without concomitant CA.

Discussion

Using a multi-center, observational cohort of 5208 individuals suffering from AMI, we observed an apparently higher TyG level in AMI populations developing CS than in those without CS. The TyG index exhibited a moderate ability to discriminate individuals occurring CS from the general AMI populations. Moreover, elevated TyG levels were strongly associated with heightened risks regarding both in-hospital and ICU mortality among those who had AMICS, even following controlling for potential confounders and employing several statistical approaches. Collectively, our findings illustrate the previously unacknowledged significance of TyG index for AMICS, thereby improving the comprehension of its involvement in cardiovascular conditions.

IR, TyG index, and the risk and prognosis of AMICS

The TyG index has gained considerable attention regarding the cardiovascular field in recent years due to its easily obtainable and reliable reflection of IR, compared to classical testing methods such as euglycemic hyper-insulinemic clamp and homeostasis model assessment of IR [23]. As previously meta-analyzed, the TyG index served as a dependable indicator for the occurrence and severity

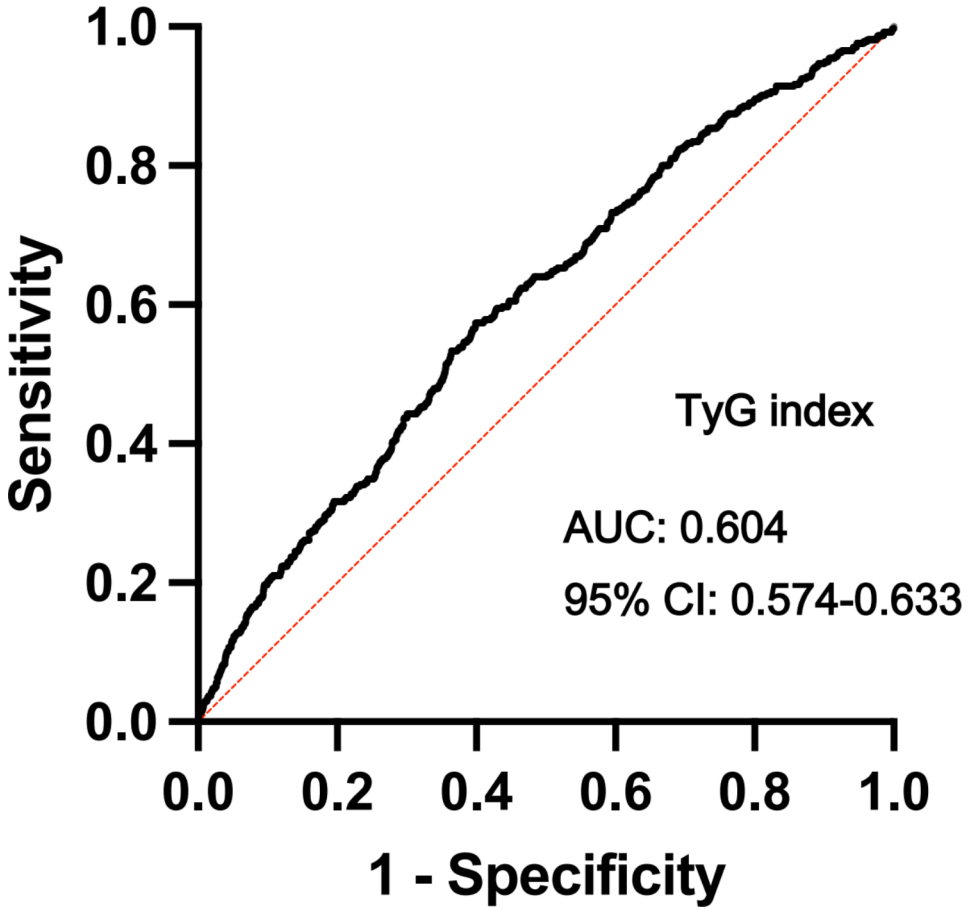

Fig. 3 ROC curve of the TyG index regarding identifying acute myocardial infarction complicated by cardiogenic shock from the overall acute myocardial infarction. ROC, receiver operator characteristic; TyG index, triglyceride-glucose index; AUC, area under the curve; CI, confidence interval

of atherosclerotic disorders in the general population [24, 25], as well as a reliable predictor for poor outcomes in individuals with coronary artery disease [26]. Moreover, associations of TyG index with other cardiovascular diseases, including but not limited to chronic heart failure [27], AMI [28], hypertension [29], coronary artery calcification [29] and atrial fibrillation have already been identified [30]. From a pathological perspective, IR can disrupt myocardial metabolism during ischemia, exacerbate endothelial dysfunction, and disturb cardiac autonomic system function [31–33]. Therefore, it is reasonable to conclude that the TyG index holds predictive value for multiple cardiovascular disorders, including its potential predictive role in AMICS as investigated in our study. Notably, elevated levels of TyG have been shown to be linked with adverse outcomes in ICU cohorts [34], who often shared partial overlap with the AMICS populations targeted by our study.

Correlation and potential mechanisms between the TyG index and AMICS

The AMICS consistently demonstrated high mortality rates, with a 30-day mortality rate of nearly 40% and a one-year mortality rate of approximately 50% [2]. Despite the proven benefits of prompt revascularization in improving prognosis, there has been no observed change in AMICS-related mortality over the past decades. In the present study, we observed apparently higher in-hospital (26.9% vs. 5.7%) and ICU mortality (22.7% vs. 3.5%) among those with AMICS. CS complicates 3–13% of cases following AMI [2–4], often presenting as a sudden manifestation following AMI, posing a life-threatening yet unpredictable situation. Established risk indicators for CS after AMI, such as advanced age, male gender, and larger infarct size have limited clinical utility due to their unmodifiable nature [2, 35]. Our findings demonstrated a significant elevation in TyG index among patients who developed CS following AMI compared to those who did not experience this complication. More notably, the TyG index demonstrated superior discriminatory ability in identifying patients at risk for developing AMICS within

Table 3 Baseline characteristics of AMI populations stratified based on the tertiles of the TyG index

Characteristics	Tertile 1 ($n=125$)	Tertile 2 ($n=125$)	Tertile 3 ($n=125$)	*P* value
Demographic data				
Age, y	71.0 (61.0–78.5)	66.0 (58.0–75.0)	65.0 (56.0–72.0)	0.007
Sex, n (%)				0.229
Male	80 (64.0)	87 (69.6)	74 (59.2)	
Female	45 (36.0)	38 (30.4)	51 (40.8)	
BMI, kg/m^2	27.3 (24.3–32.8)	28.1 (24.6–31.7)	29.6 (25.7–35.5)	0.010
Vital signs				
Heart rate, bpm	84.1 (76.1–97.3)	85.1 (78.6–98.4)	88.4 (78.8–100.5)	0.233
MAP, mmHg	74.2 (68.6–81.8)	77.3 (71.8–86.0)	76.8 (71.5–84.7)	0.033
RR, bpm	19.6 (17.1–23.3)	19.9 (17.7–22.7)	20.4 (17.4–23.6)	0.498
Temperature, ℃	36.8 (36.5–37.1)	36.8 (36.6–37.2)	36.7 (36.4–37.1)	0.078
SpO_2, %	97.1 (95.2–98.6)	97.0 (95.2–98.3)	97.3 (95.6–98.4)	0.771
Comorbidities, n (%)				
Hypertension	31 (24.8)	29 (23.2)	35 (28.0)	0.674
Diabetes mellitus	13 (10.4)	17 (13.6)	23 (18.4)	0.188
Chronic heart failure	34 (27.2)	38 (30.4)	42 (33.6)	0.546
Acute renal failure	52 (41.6)	53 (42.4)	71 (56.8)	0.025
Hepatitis	3 (2.4)	1 (0.8)	1 (0.8)	0.444
Stroke	9 (7.2)	8 (6.4)	9 (7.2)	0.960
COPD	13 (10.4)	10 (8.0)	9 (7.2)	0.641
Cardiac arrest	24 (19.2)	34 (27.2)	44 (35.2)	0.018
Chronic kidney disease	16 (12.8)	20 (16.0)	18 (14.4)	0.771
Laboratory data				
WBC, M/mcl	12.1 (8.7–14.7)	14.5 (11.9–17.9)	35 (28.0)	0.674
RBC, K/mcl	4.0 (3.5–4.4)	4.2 (3.7–4.7)	23 (18.4	0.188
PLT, K/mcl	201.2 (166.1–246.5)	198.0 (165.0-243.3)	212.4 (167.8–268.5)	0.546
Hb, g/dL	12.2 (10.4–13.7)	12.6 (11.0-13.9)	12.5 (10.6-14.0)	0.025
ALT	61.0 (35.4–126.5)	68.6 (34.0–130.4)	87.0 (41.4–194.0)	0.444
AST	158.0 (52.5–465.3)	157.5 (74.0–521.5)	210.5 (86.8–516.7)	0.960
BUN	22.8 (16.0–36.0)	21.3 (16.1-34.5)	22.3 (17.0–31.9)	0.641
Creatinine	1.2 (0.9–1.7)	1.2 (0.9–1.9)	1.3 (1.1–2.1)	0.018
CK-MB	36.1 (11.2–194.1)	85.8 (18.3–237.5)	107.0 (21.7–247.6)	0.771
LAC	1.9 (1.4–3.3)	2.4 (1.6–3.8)	3.7 (2.4-6.8)	< 0.001
NT-pro BNP	1158.6 (301.0–15264.0)	2466.5 (897.8–5457.0)	569.0 (231.3–1856.8)	0.157
FBG	129.0 (108.5–160.5)	154.0 (137.5-210.5)	281.0 (197.0–384.5)	< 0.001
TG	79.0 (61.5–98.5)	124.0 (99.0–153.5)	191.0 (129.0–274.5)	< 0.001
TyG index	8.6 (8.3-8.8)	9.2 (9.1–9.4)	10.0 (9.7–10.5)	< 0.001
TC	137.5 (107.5–168.8)	139.5 (122.0–163.5)	162.0 (127.5–185.5)	0.004
HDL-C	41.0 (36.0–51.0)	38.0 (30.0–48.0)	36.5 (28.0–45.0)	0.011
LDL-C	75.5 (51.0–96.1)	76.0 (61.3–95.5)	87.8 (60.0–112.0)	0.186
INR	1.3 (1.1–1.6)	1.2 (1.1–1.4)	1.2 (1.1–1.4)	0.682
Sodium	138.5 (136.0–141.0)	138.5 (136.0–140.4)	138.5 (136.0–140.5)	0.847
Potassium	4.0 (3.8–4.4)	4.2 (3.8–4.5)	4.1 (3.7–4.6)	0.369
APS score	45.5 (34.5–65.0)	50.0 (34.5–67.0)	68.0 (42.0–95.8)	< 0.001
Therapy data, n (%)				
CABG	9 (7.2)	13 (10.4)	8 (6.4)	0.467
PCI	35 (28.0)	39 (31.2)	41 (32.8)	0.704
IMV	38 (30.4)	48 (38.4)	60 (48.0)	0.017
Epinephrine	5 (4.0)	6 (4.8)	18 (14.4)	0.017
Norepinephrine	43 (34.4)	48 (38.4)	58 (46.4)	0.142

Table 4 Clinical outcomes of AMI populations stratified based on the tertiles of the TyG index

Outcomes	Tertile 1 (*n* = 125)	Tertile 2 (*n* = 125)	Tertile 3 (*n* = 125)	*P* value
Primiary outcomes, n (%)				
In-hospital mortality	27 (21.6)	26 (20.8)	48 (38.4)	0.002
ICU mortality	24 (19.2)	21 (16.8)	40 (32.0)	0.009
Secondary outcomes, days				
LOS-H	7.9 (4.5–15.8)	9.3 (5.4–18.6)	9.9 (4.6–18.9)	0.277
LOS-ICU	4.1 (1.9–8.2)	5.1 (3.0-9.1)	5.6 (2.5–12.1)	0.037

the overall population with AMI when compared to age, gender, BMI, CK-MB, NT-pro BNP, and certain serum lipid levels.

Massive myocardial infarction and malignant arrhythmia are significant risk factors for CS following AMI [2], contributing not only to permanent infarction but also to temporary myocardial dysfunction. Interestingly, an elevated TyG level is greatly correlated with larger infarct size and various arrhythmia including not only ventricular fibrillation examined in our study (adjusted OR: 1.331 of AMI population and 1.824 of AMICS population, Table S10) but also QT interval prolongation and atrial fibrillation as previously documented [22, 36, 37], which partially explain the relationship of TyG levels with the occurrence and outcomes of AMICS. Myocardial stunning is characterized by temporary cardiomyocyte

Table 5 Logistic regression analyses for the association between the TyG index and mortality in the AMICS population

Variables	Model 1		Model 2		Model 3	
	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value
In-hospital mortality						
Per 1 Unit increase	1.482 (1.114–1.971)	0.007	1.591 (1.182–2.143)	0.002	1.589 (1.161–2.173)	0.004
Tertile 1	1 (Reference)	-	1 (Reference)	-	1 (Reference)	-
Tertile 2	0.953 (0.520–1.749)	0.877	1.056 (0.569–1.958)	0.863	1.058 (0.553–2.023)	0.865
Tertile 3	2.263 (1.295–3.953)	0.004	2.593 (1.443–4.660)	0.001	2.544 (1.362–4.754)	0.003
P for trend	0.002	-	< 0.001	-	0.004	-
ICU mortality						
Per 1 Unit increase	1.426 (1.058–1.921)	0.020	1.456 (1.069–1.983)	0.017	1.417 (1.020–1.970)	0.038
Tertile 1	1 (Reference)	-	1 (Reference)	-	1 (Reference)	-
Tertile 2	0.850 (0.445–1.622)	0.622	0.948 (0.489–1.838)	0.875	1.026 (0.508–2.074)	0.943
Tertile 3	1.980 (1.106–3.546)	0.022	1.988 (1.076–3.673)	0.028	1.978 (1.015–3.856)	0.045
P for trend	0.011	-	0.018	-	0.045	-

TyG index, triglyceride-glucose index; OR, odds ratio; CI, confidence interval

Model 1: unadjusted

Model 2: Adjusted for age, gender, and body mass index

Model 3: Adjusted for age, gender, body mass index, mean arterial pressure, temperature, hypertension, diabetes mellitus, cardiac arrest, chronic kidney disease, stroke, white blood cell, red blood cell, alanine transaminase, aspartate transaminase, blood urea nitrogen, creatinine, creatine kinase-myocardial band, lactate, high density lipoprotein cholesterol, international normalized ratio, percutaneous coronary intervention, and coronary artery bypass grafting

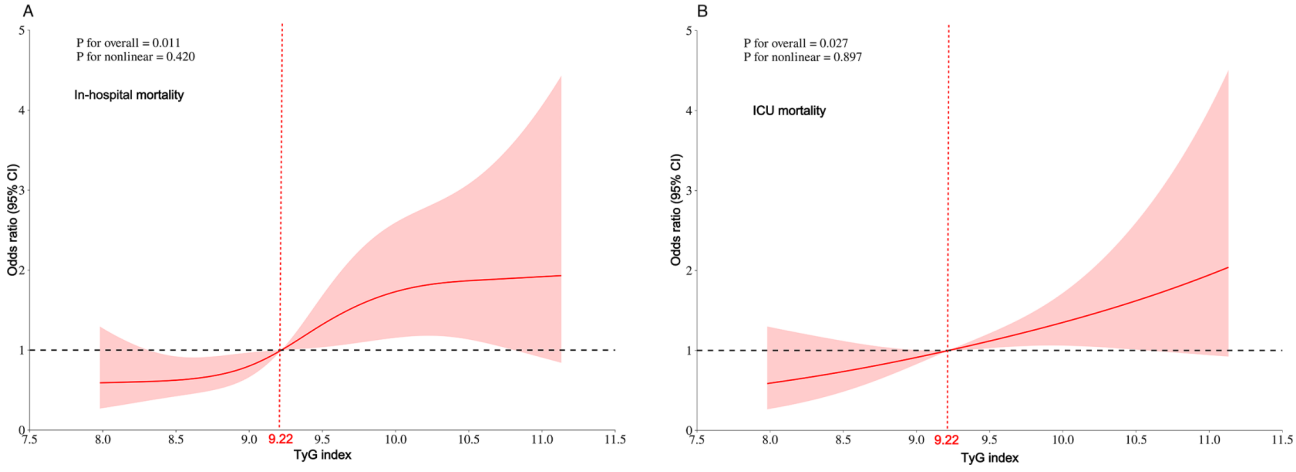

Fig. 4 RCS curves of the TyG index in relation to mortality among patients with acute myocardial infarction complicated by cardiogenic shock. **A** in-hospital mortality; **B** ICU mortality. ICU, intensive unit care; TyG index, triglyceride-glucose index; CI, confidence interval

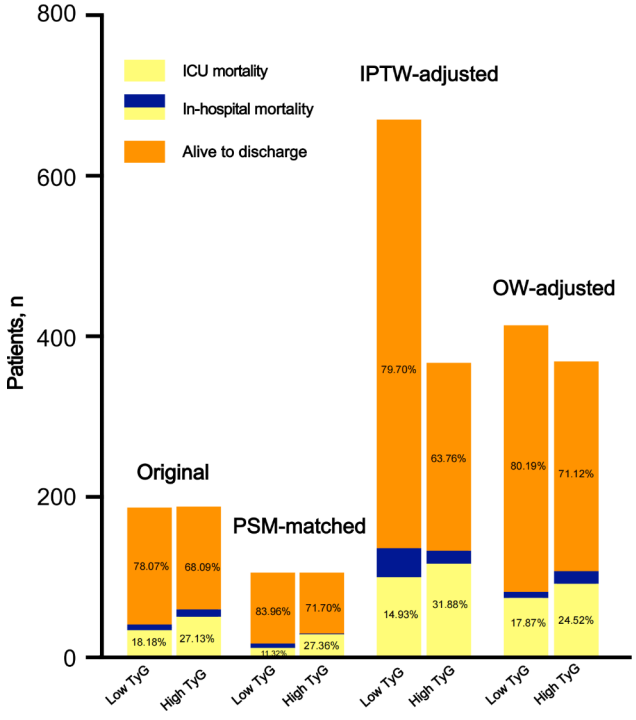

Fig. 5 The comparison of ICU mortality, in-hospital mortality, and alive to discharge rates between the lower and higher TyG index groups in the original, PSM-matched, IPTW-adjusted, and OW-adjusted AMICS populations. ICU, intensive unit care; TyG, triglyceride-glucose; PSM, propensity score matching; IPTW, inverse probability of treatment weighting; OW, overlap weighting

dysfunction without necrosis, and it has been demonstrated to play a role in the advancement of AMICS [38]. This dysfunction can be alleviated after euglycemic insulin clamp [39], suggesting a potential link between elevated TyG index and AMICS might be partially established via the exacerbation of myocardial stunning. Additionally, researchers have identified a significant correlation between elevated TyG index and coronary slow flow that has been linked to increased risk of major cardiovascular adverse events post-AMI [40–42], potentially due to diminished coronary flow reserve and endothelial dysfunction [43, 44]. These findings indicate that patients with a higher TyG index who have suffered from AMI may be at a hazardous and susceptible status for developing CS, whereas further validation is required in prospective cohorts or randomized controlled trials. Established scoring systems for assessing the severity of illness in the ICU, for instance, APACHE II score, have been proved to be an effective stratification tool for the AMICS population [45, 46]. Nevertheless, implementing these scoring systems practically remains challenging due to the need for collecting multiple physiological measures [47]. Surprisingly, we found an apparent association of TyG levels with APS scores in the AMICS population, which is a component of APACHE II focusing on acute physiological abnormalities assessment. Given these findings, it can be inferred that individuals with higher TyG index face more serious conditions in AMICS. Additionally, although there was a noticeable trend of increased LOS-ICU with higher TyG index levels, no consistent conclusions regarding this association were found in further adjusted cohort. Herein, we do not consider so yet that the TyG index was linked with the LOS-H nor LOS-ICU in patients with AMICS.

Disturbance of glucose metabolism is commonly seen in critically illness patients [48, 49]. Numerous reports from ICU cohorts have independently demonstrated poor outcomes relevant to glucose disorders [50–52]. For the past few years, scholars have established some scores to assess the severity and clinical outcomes of AMICS population such as IABP-Shock II score [35], Card Shock score [2], and residual SYNTAX score [53]. These scoring systems incorporate variables related to glucose

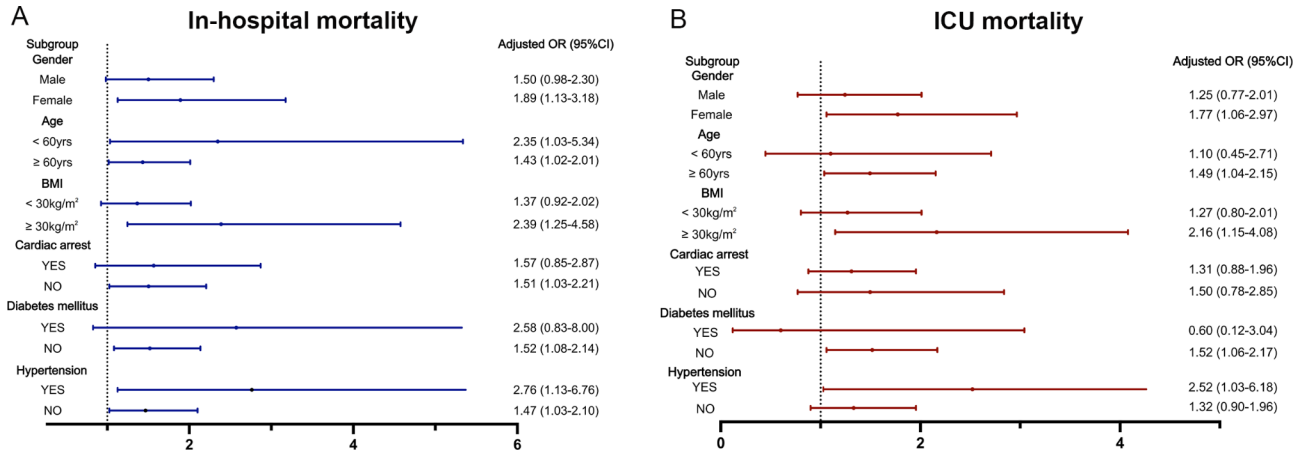

Fig. 6 Subgroup analyses for the association between the TyG index and mortality. based on age, gender, BMI, cardiac arrest, diabetes mellitus, and hypertension. **A** in-hospital mortality; **B** ICU mortality. BMI, body mass index

metabolism such as FBG, and have shown strong predictive capability by combining risk indicators, including age, gender, stroke, Cr, LAC, MAP, etc. In addition, the use of vasoactive agents, the use of mechanical circulatory support, number of diseased vessels, and TIMI after PCI were also employed as predictors for adverse prognosis in patients with AMICS. In this regard, it was not unexpected, because former studies have previously pointed the correlation of admission hyperglycemia with adverse outcomes in patients undergoing extracorporeal membrane oxygenation for AMICS [10], while this elevated glucose level was very likely to appear as a presentation of IR [54]. In the present work, we carefully considered confounding factors to maximize the reliability of our findings.

To the best of our knowledge, this study represents the first attempt to assess the correlation of the TyG index with the incidence and prognosis of CS in patients with AMI. It amalgamates data from two large cohorts, encompassing records from 209 medical centers, offering a novel perspective on the relevance of TyG index to cardiovascular disorders. As an easily and inexpensively available indicator calculated from routine tests, the TyG index is readily obtainable for the majority of AMI patients. Given the explored significant association between the TyG index and AMICS, healthcare professionals can widely and promptly utilize this index to monitor the metabolic status of patients with AMI/AMICS in various clinical settings, allowing for duly implementation of lifestyle interventions or adjustment of therapy strategies to reduce its level, thereby contributing to minimizing the occurrence of CS following AMI and maximizing the benefits for patients with AMICS. Additionally, incorporating the TyG index into future scoring systems for AMICS to measure the risk of glucolipid metabolism has the potential to enhance the overall cardiovascular risk assessment capacity for these populations. However, further explorations are needed to illustrate the causal association between the two.

Study limitation

There were some limitations that need to be acknowledged. Firstly, the retrospective design of this study limits its control over the temporal sequence of events, thereby precluding the establishment of a definitive causal relationship between the TyG index and the occurrence and prognosis of AMICS. Thus, further prospective research and randomized controlled trials are required to probe the causality of an elevation of TyG in the AMI population with increased risk and worse prognosis of CS; Secondly, despite we have controlled for confounders as much as possible, there are still certain variables that were not included in this study, such as no-reflow events, door-to-balloon time, AMI location, and so on, which have been identified as significant risk factors for the prognosis of AMICS patients [53]. Thus, there might be potential selection biases in our study, and future studies with access to more detailed clinical data are essential; Thirdly, this study is primarily grounded in historical data and may exhibit slight variations from current clinical practices and disease development trends; Fourthly, given that surrogate of IR is considered a general marker of poor prognosis for multiple disorders, the TyG index thus demonstrates diminished precise diagnostic value for a specific and well-defined pathological setting. Therefore, despite the TyG index serving as a dependable screening tool for AMICS, the relatively low diagnostic specificity value of this index should be likewise acknowledged; Furthermore, an elevated TyG has been recognized as an independent risk indicator for adverse long-term cardiovascular outcomes following AMI [55]. Hence, as a substage of AMI, additional longer follow-up studies regarding AMICS is indispensable, which will be pivotal in delving into the correlation between the TyG index and the long-term prognosis among the AMICS population.

Conclusion

The TyG index appears to be correlated with the incidence and unfavorable prognosis of CS following AMI. Patients occurring AMICS with higher TyG levels exhibit elevated in-hospital and ICU mortality rates. Our study highlights a previously undisclosed role of the TyG index in regard to AMICS as an independent risk indicator. Further larger-scale research is warranted to determine whether recognition or intervention targeting elevated TyG index can positively impact clinical outcomes in this population.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12933-024-02423-8.

Supplementary Material 1.

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None.

Author contributions

HRL and LSW contributed to writing manuscript and creating figures and tables. XZ contributed to investigation and data curation. XH and ZTD contributed to create figures and tables. CLL and HW contributed to review of all and final revisions. XTH provided resources and performed statistical analysis. All authors have read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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