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Association between triglyceride glucose body mass index and 1 year all cause mortality in stage 4 CKM syndrome patients

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The triglyceride-glucose body mass index (TyG-BMI) is acknowledged as a dependable surrogate biomarker for the evaluation of insulin resistance (IR). Current research indicates a significant correlation between TyG-BMI and the risk of subsequent cardiovascular events in individuals diagnosed with cardiovascular-kidney-metabolic syndrome (CKM) at stages 0–3. Nevertheless, the prognostic significance of TyG-BMI in patients with CKM stage 4 has not been extensively investigated, and there is a paucity of evidence available on this topic. The study utilized patient data from the Medical Information Mart for Intensive Care (MIMIC-IV) database, categorizing the data into quartiles based on the TyG-BMI index. The primary outcomes of interest were all-cause mortality at 180 days and at one year. To assess the relationship between the TyG-BMI index and these outcomes in patients diagnosed with stage 4 CKM, a Cox proportional hazards model was employed. Additionally, a restricted cubic splines(RCS) model was applied to further investigate the associations between the TyG-BMI index and the specified outcomes. A total of 1,885 patients participated in the study, with 62.49% of the cohort being male. The all-cause mortality rates were recorded at 30.50% at 180 days and 35.12% at one year. Analysis using a multivariate Cox proportional hazards model revealed that an increase in the TyG-BMI index was significantly correlated with a reduction in the risk of all-cause mortality at both the 180-day and one-year marks. Specifically, for each standard deviation increase in the TyG-BMI index, the risk of all-cause mortality decreased by 17% within 180 days (HR = 0.83, 95% CI: 0.76–0.91) and by 21% within one year (HR = 0.79, 95% CI: 0.71–0.87). Furthermore, regression analysis utilizing RCS indicated a linear decrease in all-cause mortality rates associated with increasing TyG-BMI index values over both the 180-day and one-year periods (P for nonlinearity = 0.171 and P for nonlinearity = 0.141, respectively). In patients diagnosed with stage 4 CKM syndrome, a reduced TyG-BMI index was found to be significantly correlated with a heightened risk of all-cause mortality within both 180 days and one year. Consequently, the TyG-BMI index may be utilized as an effective instrument for risk stratification and prognostic assessment in this patient population.

Keywords Cardiovascular-Kidney-Metabolic syndrome, The triglyceride-glucose body mass index, Insulin resistance, Obesity paradox

Abbreviations

AF	Atrial fibrillation
AG	Anion gap
ARF	Acute renal failure
ATP	Adenosine triphosphate
BUN	Blood urea nitrogen
Ca^{2+}	Calcium, total
CKD	Chronic kidney disease
CKM	Cardiovascular-kidney-metabolic
CL^-	Chloride
CREA	Creatinine

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CVD	Cardiovascular diseases
eGFR	Estimated glomerular filtration rate
GLU	Glucometer
HCT	Hematocrit
HF	Heart failure
HGB	Hemoglobin
HOMA-IR	Homeostasis model assessment of insulin resistance
INR	International normalized ratio
IR	Insulin resistance
K^+	Potassium
LVEF	Left ventricular ejection fraction
MIT	Massachusetts Institute of Technology
MS	Metabolic syndrome
NA^+	Sodium
PGC-1α	Proliferator-activated receptor γ coactivator 1α
PLT	Platelet count
PPARα	Peroxisome proliferator-activated receptor α
RBC	Red blood cell count
RCS	Restricted cubic splines
RDW	Red blood cell distribution width
SD	Standard deviations
TG	Triglyceride
TSH	Thyroid-stimulating hormone
TyG	Triglyceride-glucose
TyG-BMI	The triglyceride-glucose body mass index
WBC	White blood cell count

In 2023, the American Heart Association (AHA) introduced the concept of cardiovascular-kidney-metabolic syndrome (CKM) to enhance multidisciplinary approaches for the prevention, risk stratification, and management of cardiovascular diseases (CVD), chronic kidney disease (CKD), and metabolic disorders[1]. The CKM syndrome framework highlights the complex interactions and reciprocal exacerbation among CVD, CKD, and metabolic disorders[2]. As the disease progresses, various pathophysiological mechanisms contribute to a detrimental cycle, particularly leading to a significant increase in CVD risk[3]. Current reports indicate that approximately 90% of adults in the United States are affected by CKM, with the prevalence of advanced stages (stage 3 or 4) increasing with age; specifically, among individuals aged 65 and older, the prevalence of advanced CKM is reported to be 55.3%. With the ongoing global trend of population aging, the burden of CKM is expected to escalate worldwide[4]. For patients in stage 4, it is crucial to prioritize the provision of high-quality diagnostic and therapeutic services, as well as to reduce the recurrence and mortality associated with CVD through effective secondary prevention strategies[5–8]. Consequently, identifying high-risk populations and enhancing their management to improve prognostic outcomes is of utmost importance. Previous research has not adequately examined the relationship between effective clinical markers and adverse outcomes in stage 4 CKM. Therefore, further investigation into prognostic indicators that can predict adverse risks in stage 4 CKM is critically needed.

Insulin resistance (IR) is a common feature in a range of metabolic disorders. Prior research has established a significant link between IR and the pathogenesis of CVD, CKD, and other related conditions[9,10]. The widely utilized homeostasis model assessment of insulin resistance (HOMA-IR) may not provide an accurate representation of insulin resistance in individuals with compromised pancreatic β-cell function[11]. In contrast, the TyG index proposed by Simental-Mendía LE et al. has more advantages as an alternative indicator of IR[12]. Recent studies suggest that the integration of the TyG index with the obesity metric, body mass index (BMI), markedly improves the precision of IR assessment[13]. A multitude of studies has demonstrated a positive correlation between the TyG-BMI index and the occurrence of various diseases, including stroke, coronary heart disease, sepsis, and depression[14–17]. Nevertheless, there is a notable gap in the literature regarding the relationship between the TyG-BMI index and the prognosis of patients diagnosed with stage 4 CKM syndrome.

Consequently, we conducted a retrospective cohort study to examine the relationship between the TyG-BMI index and mortality rates at 180 days and one year in patients diagnosed with stage 4 CKM syndrome. The findings of this investigation may offer valuable insights for optimizing the medical management of individuals with stage 4 CKM and assist in identifying those at elevated risk, ultimately improving their prognostic outcomes.

Methods

Study participants

This research employed a retrospective cohort design. The data utilized were sourced from the Medical Information Mart for Intensive Care (MIMIC-IV) database (version 3.0), which was developed through a collaboration between the Massachusetts Institute of Technology (MIT) and BIDMC. The database encompasses pertinent information regarding patients who received inpatient care at BIDMC from 2008 to 2022. Given the anonymized nature of the patient health information contained within this database, informed consent from patients was not necessary for the conduct of this study.

This study included patients classified as stage 4 according to the Presidential Advisory Statement on CKM syndrome by the AHA. The exclusion criteria were as follows: (1) For patients with multiple hospitalizations, only data from the first hospitalization were extracted; (2) Patients with a hospital stay of less than 24 h; (3) Patients

lacking blood glucose, triglyceride, and BMI data within 24 h of admission; (4) Patients with malignant tumors or who were pregnant; (5) Patients with a TyG-BMI value exceeding the mean by three standard deviations (SD). Ultimately, a total of 1,885 patients aged 18 years or older were included in the study. Figure 1 illustrates the study flow.

Data extraction

Relevant information was extracted from the MIMIC-IV database using pgAdmin PostgreSQL (version 6.1). For this study, the following data were collected: (1) demographic information, including age, gender, BMI, and marital status; (2) laboratory test results; (3) comorbidity conditions; (4) length of hospital stay, survival status within one year of follow-up, and follow-up duration. All laboratory variables were restricted to data collected within the first 24 h post-admission. When multiple results were available, the mean value was used for processing. To mitigate potential bias, variables with missing values exceeding 10% were excluded. Variables containing missing values below 10% were imputed using the random forest method implemented in the missForest package of R software[18].

TyG-BMI index formula

TyG-BMI = BMI × TyG index, where the TyG index = ln [FPG (mg/dL) × TG (mg/dL) / 2][19].

Outcomes

The primary objective of this study is to evaluate all-cause mortality at one year, while the secondary outcome focuses on all-cause mortality at 180 days.

Statistical analysis

In this study, participants were classified into four groups (Q1-Q4) based on the quartiles of the TyG-BMI index. For continuous variables that followed a normal distribution, data were reported as mean ± SD, and statistical comparisons were conducted using analysis of variance (ANOVA). Conversely, for continuous variables that did not conform to a normal distribution, data were summarized using the median and interquartile range, with the Kruskal-Wallis H test employed for statistical analysis. Categorical variables were represented as frequency (percentage), and differences among groups were evaluated using the χ^2 test. To assess the incidence of major outcome events across varying TyG-BMI levels, Kaplan-Meier survival analysis was performed, with group differences analyzed via the log-rank test. The association between TyG-BMI and all-cause mortality within one year was prospectively examined using both univariate and multivariate Cox regression models, incorporating

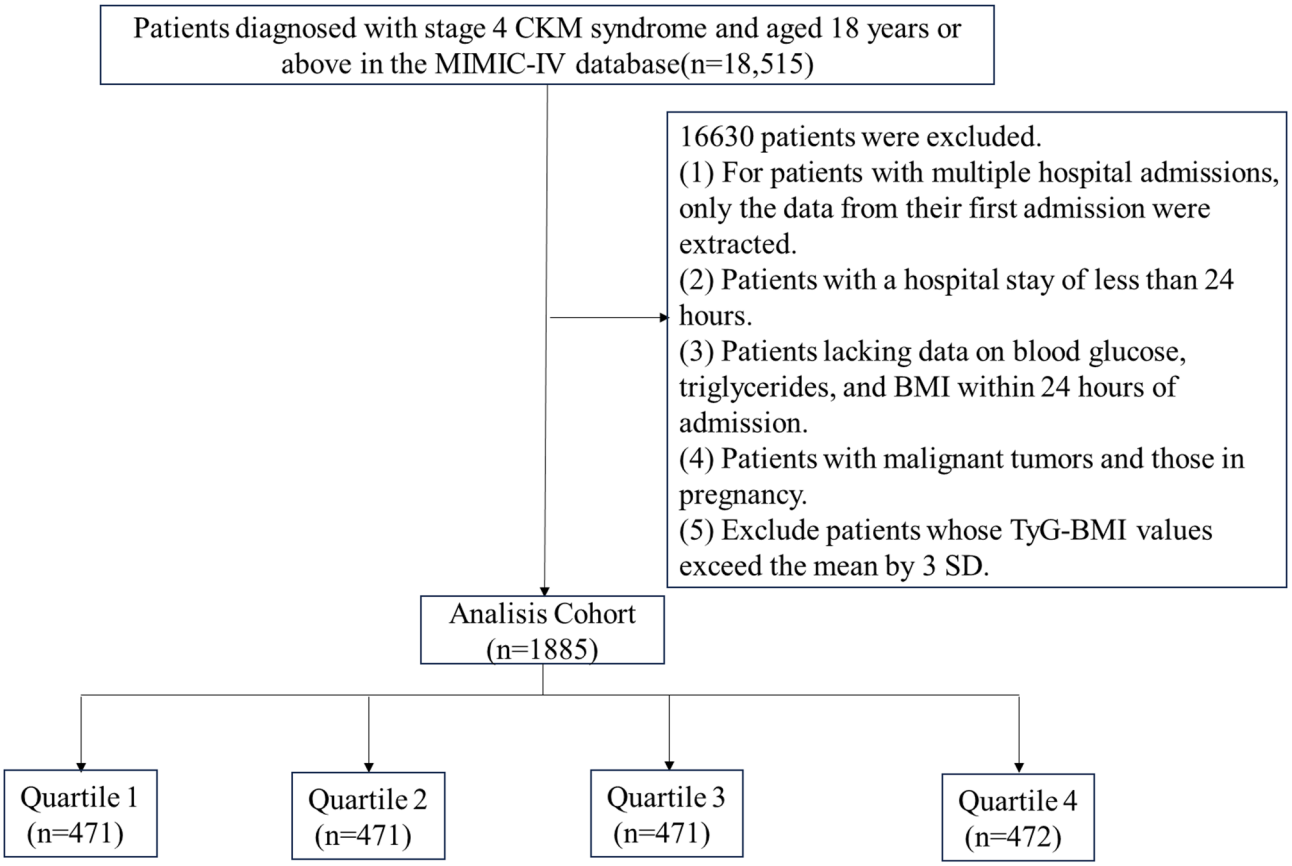

Fig. 1. Flow diagram of the patient selection process.

the TyG-BMI index as both continuous and categorical variables, with the lowest quartile serving as the reference group. To investigate the potential nonlinear association between TyG-BMI and all-cause mortality at 180 days and one year, a restricted cubic spline (RCS) regression analysis of the hazard ratio (HR) was utilized. We compared the predictive performance, sensitivity, and specificity of the TyG-BMI index, TG, BMI, and GLU in forecasting one-year all-cause mortality risk using Receiver Operating Characteristic (ROC) curve analysis. Furthermore, subgroup analyses were conducted based on several classifications, including age (≤ 65 years vs. > 65 years), gender (male vs. female), and various medical histories (acute renal failure, hypertension, acute myocardial infarction, heart failure, stroke, atrial fibrillation, and chronic kidney disease, each categorized as absent or present). The interactions between the TyG-BMI index and the stratification variables were assessed using likelihood ratio tests. Prior to these analyses, the proportional hazards assumption was verified through visual inspection of Schoenfeld residuals. Variables with a significance level of $p < 0.05$, along with baseline variables such as sex and ethnicity, were selected and incorporated into the Cox proportional hazards model. To assess multicollinearity, variance inflation factors (VIFs) were applied. A VIF exceeding 10 was considered indicative of high multicollinearity. In this study, no significant multicollinearity was observed (Supplementary Material Table 1).All statistical analyses were executed using R version 4.1.2, with statistical significance established at a two-sided P-value of < 0.05. The statistical methods of the instrumental variable approach in the sensitivity analysis are described in the Supplementary Materials.

Results

Baseline characteristics of the participants

The study comprised a total of 1,885 participants, of whom 37.51% were female, with a mean age of 68 years. Participants were categorized into four groups according to the quartiles of the TyG-BMI index: Q1 (128.95–222.56), Q2 (222.56–267.95), Q3 (267.95–324.74), and Q4 (324.74–782.33). The baseline characteristics of each group are presented in Table 1. The distribution of participants among the groups was as follows: Q1 ($n = 471$, 24.99%), Q2 ($n = 471$, 24.99%), Q3 ($n = 471$, 24.99%), and Q4 ($n = 472$, 25.04%). Notably, individuals in the higher TyG-BMI index groups tended to be younger, experienced longer hospital stays and follow-up durations, and had a greater proportion of individuals who were married, divorced, or single, in contrast to a lower proportion of widowed individuals. Furthermore, the prevalence of hypertension, heart failure, and acute renal failure was elevated in the higher TyG-BMI index groups, while the incidence of stroke was reduced. Hematological parameters, including white blood cell count, red blood cell count, platelet count, hemoglobin, red blood cell distribution width, hematocrit, potassium, blood glucose, prothrombin international normalized ratio, urea nitrogen, and creatinine levels, were significantly higher in the higher TyG-BMI index groups, whereas chloride levels were comparatively lower. The prevalence of acute myocardial infarction was greater in the Q2 and Q3 groups, while it was similar between the Q4 and Q1 groups. The one-year mortality rate exhibited a progressive decline with increasing TyG-BMI index (Q1: 42.25%, Q2: 34.18%, Q3: 35.88%, Q4: 28.18%; $P = 0.004$).

The main outcome

The Kaplan-Meier survival analysis curves for the primary outcome rates among the groups stratified by the quartiles of the TyG-BMI index are presented in Fig. 2. A significant difference in mortality was observed between the groups during the 1-year follow-up (log-rank $P < 0.001$). Additionally, a statistically significant difference in mortality was noted during the 180-day follow-up (log-rank $P = 0.006$).

Table 2 delineates three multivariable Cox proportional hazards models that assess the relationship between the TyG-BMI index and primary outcomes. These models were also constructed for the purpose of conducting sensitivity analyses. In the fully adjusted Model 3, it was found that each SD increase in the TyG-BMI index corresponded to an 17% decrease in the risk of all-cause mortality within 180 days (HR = 0.83, 95% CI: 0.76–0.91) and a 21% decrease in the risk of all-cause mortality within one year (HR = 0.79, 95% CI: 0.71–0.87). To further clarify the association between the TyG-BMI index and the primary outcomes, the TyG-BMI was stratified into quartiles. In the fully adjusted Model 3, significant differences in 180-day all-cause mortality were observed between the Q1 group and the Q2, Q3, and Q4 groups (Q1 vs. Q2: HR = 0.77 [95% confidence interval (CI) 0.61–0.96], $P = 0.020$; Q1 vs. Q3: HR = 0.78 [95% CI 0.62–0.98], $P = 0.036$; Q1 vs. Q4: HR = 0.50 [95% CI 0.38–0.65], $P < 0.001$).In terms of one-year all-cause mortality, no significant difference was identified between the Q1 and Q3 groups, yet significant differences were noted between the Q1 group and both the Q2 and Q4 groups (Q1 vs. Q2: HR = 0.77 [95% CI 0.62–0.95], $P = 0.016$; Q1 vs. Q4: HR = 0.50 [95% CI 0.39–0.65], $P < 0.001$).

To further explore the association between the quartiles of the TyG-BMI index and all-cause mortality over one year and 180 days, we performed subgroup and interaction analyses stratified by age, gender, and various comorbidities, including acute renal failure, hypertension, acute myocardial infarction, heart failure, stroke, atrial fibrillation, and chronic kidney disease (see Table 3). The findings revealed that in the subgroup analysis concerning the TyG-BMI index and the risk of all-cause mortality over one year, a significant interaction was identified exclusively in patients with acute renal failure (interaction $P < 0.001$), whereas no significant interactions were detected in the other subgroups (interaction $P > 0.05$). Comparable results were observed in the subgroup analysis regarding the TyG-BMI index and the risk of all-cause mortality over a 180-day period.

The fully adjusted RCS model revealed an "L"-shaped association between the TyG-BMI index and all-cause mortality at both one year and 180 days (refer to Fig. 3). Furthermore, the RCS regression analysis demonstrated that with an increase in the TyG-BMI index, the rates of all-cause mortality at one year and 180 days displayed a linear decreasing trend, as indicated by the nonlinear test results ($P = 0.171$ and $P = 141$, respectively).

The ROC curve demonstrated that TyG-BMI exhibited superior predictive capability for one-year all-cause mortality compared to BMI, TG, and GLU. It showed moderate predictive performance (AUC = 0.64 [95% CI: 0.62–0.67]), with an optimal cutoff value of 229.8, achieving a specificity of 68% and sensitivity of 54% (Supplementary Material Table 2).

Variables	Total ($n=1885$)	1 ($n=471$)	2 ($n=471$)	3 ($n=471$)	4 ($n=472$)	*P*-valve
TyG-BMI	267.95 (222.58, 324.63)	199.40 (182.02,210.85)	244.90 (234.07,256.48)	293.77 (278.75,307.40)	377.28 (346.39,428.71)	< 0.001
TyG	9.80 (9.32, 10.36)	9.34 (8.95,9.77)	9.60 (9.23,10.04)	9.99 (9.60,10.57)	10.36 (9.84,10.99)	< 0.001
Demographic variables						
Age (y, IQR)	68.00 (60.00, 77.00)	72.00 (62.00,82.00)	70.00 (61.00,79.00)	67.00 (60.00,75.00)	65.00 (57.75,72.00)	< 0.001
Male (n, %)	1178 (62.49)	289 (61.36)	293 (62.21)	314 (66.67)	282 (59.75)	0.151
Marital status, n (%)						< 0.001
Divorced	125 (6.63)	31 (6.58)	37 (7.86)	24 (5.10)	33 (6.99)	
Married	1172 (62.18)	283 (60.08)	300 (63.69)	300 (63.69)	289 (61.23)	
Single	384 (20.37)	82 (17.41)	83 (17.62)	101 (21.44)	118 (25.00)	
Widowed	204 (10.82)	75 (15.92)	51 (10.83)	46 (9.77)	32 (6.78)	
BMI	29.39 (25.06, 34.46)	22.48 (20.74,24.33)	27.40 (26.00,29.08)	31.26 (29.82,33.23)	38.76 (35.95,44.44)	< 0.001
Race (n,%)						0.630
White	1088 (57.72)	275 (58.39)	257 (54.56)	272 (57.75)	284 (60.17)	
Black	175 (9.28)	38 (8.07)	48 (10.19)	44 (9.34)	45 (9.53)	
Other	622 (33.00)	158 (33.55)	166 (35.24)	155 (32.91)	143 (30.30)	
Comorbidities						
Hypertension (n, %)	829 (43.98)	214 (45.44)	226 (47.98)	213 (45.22)	176 (37.29)	0.006
AMI (n,%)	621 (32.94)	143 (30.36)	156 (33.12)	179 (38.00)	143 (30.30)	0.039
HF (n,%)	1138 (60.37)	285 (60.51)	255 (54.14)	277 (58.81)	321 (68.01)	< 0.001
Stroke (n,%)	445 (23.61)	133 (28.24)	127 (26.96)	94 (19.96)	91 (19.28)	< 0.001
AF (n,%)	756 (40.11)	199 (42.25)	176 (37.37)	180 (38.22)	201 (42.58)	0.233
ARF (n,%)	939 (49.81)	189 (40.13)	205 (43.52)	244 (51.80)	301 (63.77)	< 0.001
CKD (n,%)	539 (28.59)	144 (30.57)	124 (26.33)	132 (28.03)	139 (29.45)	0.506
Laboratory parameters						
WBC (K/μL)	11.80 (8.50, 15.70)	10.90 (7.90,14.30)	11.00 (8.20,14.85)	12.20 (8.80,16.40)	13.00 (9.67,17.80)	< 0.001
RBC (m/μL)	3.89 (3.24, 4.42)	3.68 (3.01,4.28)	3.86 (3.33,4.36)	3.96 (3.29,4.52)	4.01 (3.33,4.54)	< 0.001
PLT (K/μL)	206.00 (154.00, 262.00)	203.00 (154.00,274.00)	196.00 (145.00,250.00)	206.00 (159.00,257.50)	215.50 (165.00,273.50)	0.003
HGB (g/dL)	11.40 (9.60, 13.20)	11.10 (9.10,12.85)	11.70 (10.00,13.30)	11.50 (9.65,13.40)	11.40 (9.70,13.20)	0.001
RDW (%)	14.30 (13.40, 15.90)	14.20 (13.30,15.90)	14.00 (13.30,15.40)	14.20 (13.30,15.70)	14.60 (13.70,16.40)	< 0.001
HCT (%)	35.00 (29.60, 39.80)	33.50 (27.70,38.50)	35.20 (30.95,40.00)	35.30 (29.70,40.25)	35.40 (30.50,40.40)	< 0.001
NA^+ (mEq/L)	139.00 (136.00, 141.00)	139.00 (135.00,142.00)	139.00 (136.00,141.00)	138.00 (136.00,141.00)	138.00 (135.00,141.00)	0.235
K^+ (mEq/L)	4.20 (3.80, 4.70)	4.10 (3.70,4.70)	4.10 (3.70,4.50)	4.20 (3.80,4.60)	4.30 (3.90,4.90)	< 0.001
GA^{2+} (mg/dL)	8.50 (8.00, 8.90)	8.50 (8.00,9.00)	8.50 (8.00,9.00)	8.50 (8.00,8.90)	8.40 (7.90,8.80)	0.192
CL^- (mEq/L)	103.00 (99.00, 107.00)	104.00 (100.00,107.50)	104.00 (100.00,107.00)	103.00 (100.00,107.00)	102.00 (98.00,106.00)	< 0.001
GLU (mg/dL)	140.00 (112.00, 192.00)	126.00 (103.00,161.50)	134.00 (107.00,178.00)	151.00 (118.00,204.50)	163.00 (123.75,244.50)	< 0.001
AG (mEq/L)	14.00 (12.00, 17.00)	14.00 (12.00,17.00)	14.00 (12.00,17.00)	15.00 (13.00,17.00)	15.00 (12.00,18.00)	0.051
INR	1.20 (1.10, 1.50)	1.20 (1.10,1.50)	1.20 (1.10,1.50)	1.30 (1.10,1.50)	1.30 (1.10,1.60)	0.030
TG (mmol/L)	121.00 (85.00, 181.00)	86.00 (64.00,122.50)	107.00 (81.00,144.00)	139.00 (99.50,203.50)	173.50 (120.75,282.00)	< 0.001
BUN (mg/dL)	22.00 (15.00, 37.00)	22.00 (16.00,36.00)	21.00 (14.00,33.00)	22.00 (16.00,37.50)	24.00 (16.00,43.25)	0.001
CREA (mg/dL)	1.20 (0.90, 1.80)	1.10 (0.80,1.60)	1.10 (0.80,1.60)	1.20 (0.90,1.85)	1.20 (0.90,2.10)	< 0.001
Outcomes						
Length of hospital stay (d)	11.92 (6.00, 22.87)	10.24 (5.78,19.94)	10.07 (5.68,19.32)	12.10 (5.74,23.13)	14.95 (7.65,28.52)	< 0.001
Follow-up time (d)	365.00 (59.00, 365.00)	365.00 (42.50,365.00)	365.00 (82.50,365.00)	365.00 (47.00,365.00)	365.00 (74.50,365.00)	0.032
One-year mortality rate (n, %)	662 (35.12)	199 (42.25)	161 (34.18)	169 (35.88)	133 (28.18)	< 0.001

Table 1. Baseline characteristics of individuals classified by quartiles of the TyG-BMI index. Data are presented as the mean (SD), median (quantile1, quantile3) or number (%), Triglyceride-glucose (TyG), triglyceride-glucose to body mass index (TyG-BMI), Body Mass Index (BMI), acute myocardial infarction (AMI), heart failure (HF), atrial fibrillation (AF), acute renal failure (ARF), chronic kidney disease (CKD), white blood cell count (WBC), red blood cell count (RBC), platelet count (PLT), hemoglobin (HGB), red blood cell distribution width (RDW), hematocrit (HCT), sodium (NA^+), potassium (K^+), calcium, total (CA^{2+}), chloride (CL^-), glucometer (GLU), anion gap (AG), international normalized ratio (INR), triglyceride (TG), blood urea nitrogen (BUN), creatinine (CREA).

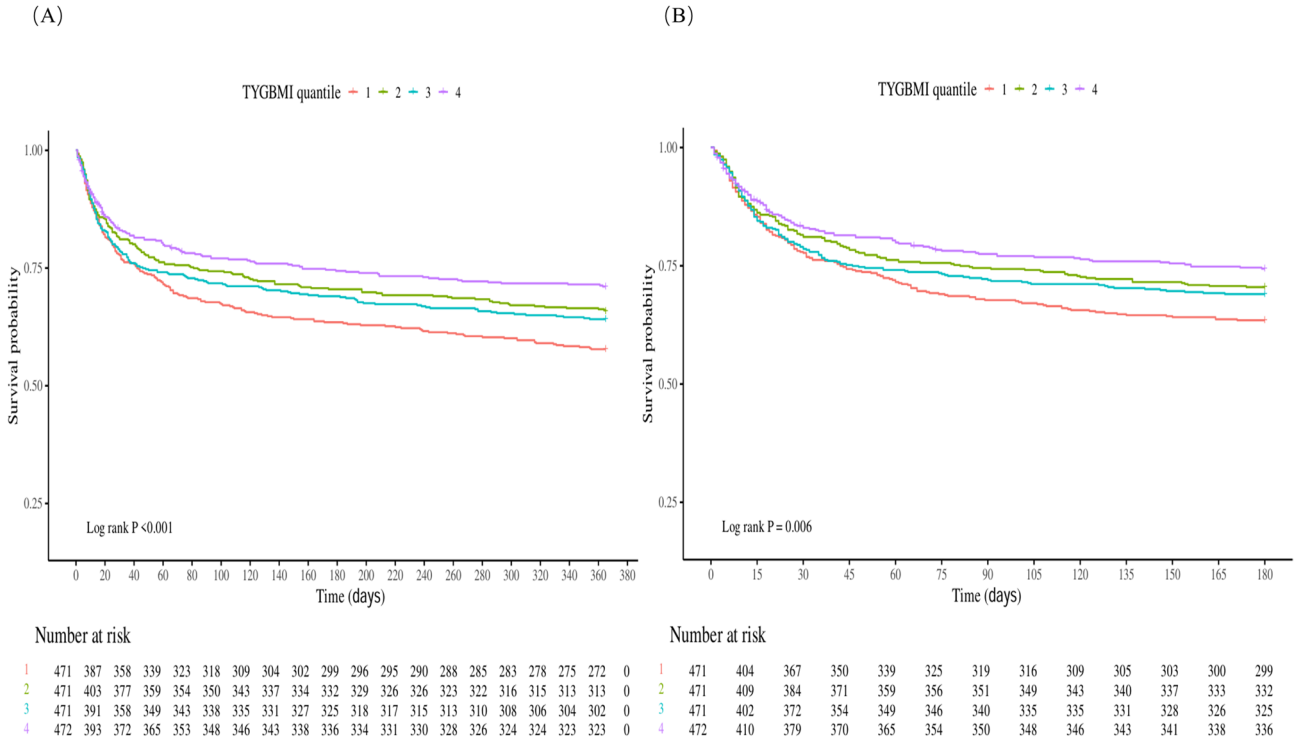

Fig. 2. Kaplan-Meier analyses for different endpoints among the quartiles of the triglyceride-glucose to body mass index (TyG-BMI) index. (**A**) One-year all-cause mortality rate; (**B**) 180-day all-cause mortality rate.

Categories	Model 1		Model 2		Model 3	
	HR (95% CI)	*P*-value	HR (95% CI)	*P*-value	HR (95% CI)	*P*-value
180 days mortality						
TyG-BMI (per SD change)	0.87 (0.80–0.95)	0.002	0.83 (0.76–0.90)	< 0.001	0.83 (0.76–0.91)	<0.001
Quartile						
Q1 (*N* = 471)	1.00 (reference)		1.00 (reference)		1.00 (reference)	
Q2 (*N* = 471)	0.78 (0.62–0.97)	0.028	0.79 (0.63–0.99)	0.037	0.76 (0.61–0.96)	0.020
Q3 (*N* = 471)	0.83 (0.67–1.04)	0.105	0.81 (0.65–1.01)	0.065	0.78 (0.62–0.98)	0.036
Q4 (*N* = 472)	0.66 (0.53–0.84)	< 0.001	0.59 (0.46–0.75)	< 0.001	0.50 (0.38–0.65)	< 0.001
1 year mortality						
TyG-BMI (per SD change)	0.86 (0.79–0.94)	< 0.001	0.83 (0.76–0.91)	< 0.001	0.79 (0.71–0.87)	< 0.001
Quartile						
Q1 (*N* = 471)	Reference		1.00 (Reference)		1.00 (Reference)	
Q2 (*N* = 471)	0.77 (0.63–0.95)	0.014	0.79 (0.64–0.97)	0.028	0.77 (0.62–0.95)	0.016
Q3 (*N* = 471)	0.83 (0.67–1.01)	0.069	0.83 (0.67–1.02)	0.073	0.81 (0.65–1.00)	0.051
Q4 (*N* = 472)	0.64 (0.51–0.80)	< 0.001	0.58 (0.46–0.73)	< 0.001	0.50 (0.39–0.65)	< 0.001

Table 2. Correlation between the TyG-BMI index and the one-year all-cause mortality rate as well as the 180-day all-cause mortality rate in the population with stage 4 CKM syndrome. Model 1: crude model. Model 2: adjusted according to age, gender, BMI, race, marital status, hypertension, AMI, HF, stroke, and ARF. Model 3: adjusted according to age, gender, BMI, race, marital status, hypertension, AMI, HF, stroke, ARF, WBC, RBC, PLT, HGB, RDW, HCT, K^+, GA^{2+}, CL^-, GLU, INR, TG, BUN, and CREA.

Sensitivity analysis

To test the robustness of the association, we performed a series of sensitivity analyses. First, to verify whether missing value imputation introduced potential bias, a fully adjusted multivariate Cox analysis was performed after excluding samples with missing key variables. The results consistently demonstrated that higher TyG-BMI levels remained associated with lower risks of one-year and 180-day all-cause mortality, with no significant changes observed (Supplementary Material Table 3). Second, TyG-BMI was categorized into three groups using the 33rd percentile (P33) and 67th percentile (P67) as cutoff points. Repeating the primary analysis under

(A)								
		Q2		Q3		Q4		
Subgroups	Q1	HR (95%CI)	P value	HR (95%CI)	P value	HR (95%CI)	P value	P for interaction
Age, years								
≤65	Ref	0.838 (0.623,1.128)	0.244	0.908 (0.610,1.351)	0.633	0.487 (0.250,0.951)	0.035	0.136
>65	Ref	0.758 (0.485,1.183)	0.222	0.828 (0.480,1.427)	0.496	0.775 (0.326,1.841)	0.564	
Sex								
Male	Ref	0.920 (0.697,1.215)	0.556	0.830 (0.628,1.096)	0.189	0.485 (0.351,0.670)	<0.001	0.941
Female	Ref	0.721 (0.514,1.009)	0.056	0.848 (0.605,1.187)	0.335	0.615 (0.431,0.876)	0.007	
Race								
White	Ref	0.81 (0.62 ~ 1.07)	0.144	0.73 (0.55 ~ 0.97)	0.030	0.44 (0.32 ~ 0.62)	< 0.001	0.051
Black	Ref	1.08 (0.46 ~ 2.52)	0.865	1.27 (0.55 ~ 2.92)	0.570	0.50 (0.18 ~ 1.41)	0.189	
Other	Ref	0.64 (0.43 ~ 0.95)	0.026	0.78 (0.53 ~ 1.14)	0.198	0.60 (0.39 ~ 0.93)	0.022	
ARF								
Yes	Ref	0.935 (0.705,1.241)	0.641	0.882 (0.666,1.167)	0.379	0.572 (0.425,0.769)	<0.001	<0.001
No	Ref	0.680 (0.485,0.953)	0.025	0.909 (0.643,1.285)	0.591	0.467 (0.302,0.723)	<0.001	
Hypertension								
Yes	Ref	0.742 (0.527,1.044)	0.087	0.790 (0.555,1.125)	0.192	0.382 (0.249,0.587)	<0.001	0.071
No	Ref	0.906 (0.687,1.194)	0.483	0.918 (0.697,1.209)	0.542	0.630 (0.471,0.843)	0.002	
AMI								
Yes	Ref	1.211 (0.802,1.827)	0.362	0.777 (0.500,1.206)	0.260	0.758 (0.467,1.230)	0.262	0.709
No	Ref	0.732 (0.563,0.951)	0.020	1.002 (0.766,1.313)	0.986	0.564 (0.405,0.784)	<0.001	
HF								
Yes	Ref	0.704 (0.537,0.922)	0.011	0.855 (0.662,1.104)	0.230	0.581 (0.442,0.764)	<0.001	0.749
No	Ref	1.093 (0.766,1.559)	0.624	0.841 (0.560,1.263)	0.404	0.383 (0.234,0.626)	<0.001	
Stroke								
Yes	Ref	0.984 (0.640,1.512)	0.941	1.107 (0.706,1.736)	0.658	0.562 (0.829,1.907)	0.033	0.930
No	Ref	0.761 (0.594,0.975)	0.031	0.779 (0.610,0.996)	0.046	0.521 (0.392,0.668)	<0.001	
AF								
Yes	Ref	0.741 (0.546,1.005)	0.054	0.770 (0.570,1.040)	0.088	0.449 (0.319,0.632)	<0.001	0.311
No	Ref	0.893 (0.660,1.206)	0.460	0.889 (0.663,1.219)	0.492	0.604 (0.432,0.844)	0.003	
CKD								
Yes	Ref	1.069 (0.755,1.514)	0.707	0.981 (0.684,1.407)	0.919	0.580 (0.392,0.860)	0.007	0.799
No	Ref	0.694 (0.528,0.913)	0.009	0.787 (0.599,1.034)	0.085	0.489 (0.361,0.662)	<0.001	
(B)								
		Q2		Q3		Q4		
Subgroups	Q1	HR(95%CI)	P value	HR(95%CI)	P value	HR(95%CI)	P value	P for interaction
Age, years								
≤65	Ref	0.690 (0.446,1.067)	0.095	0.651 (0.429,0.998)	0.044	0.397 (0.256,0.616)	<0.001	0.102
>65	Ref	0.913 (0.694,1.200)	0.513	1.002 (0.756,1.328)	0.990	0.664 (0.485,0.910)	0.011	
Sex								
Male	Ref	0.895 (0.666,1.204)	0.464	0.809 (0.602,1.086)	0.809	0.481 (0.342,0.677)	<0.001	0.695
Female	Ref	0.758 (0.525,1.095)	0.139	0.826 (0.570,1.198)	0.313	0.653 (0.445,0.960)	0.030	
Race								
White	Ref	0.84 (0.62 ~ 1.14)	0.258	0.73 (0.54 ~ 1.00)	0.051	0.44 (0.31 ~ 0.63)	<0.001	0.158
Black	Ref	1.46 (0.56 ~ 3.78)	0.440	1.58 (0.61 ~ 4.09)	0.342	0.78 (0.25 ~ 2.43)	0.667	
Other	Ref	0.57 (0.38 ~ 0.86)	0.007	0.68 (0.46 ~ 1.02)	0.060	0.55 (0.35 ~ 0.86)	0.009	
ARF								
Yes	Ref	0.933 (0.692,1.259)	0.651	0.896 (0.667,1.204)	0.466	0.581 (0.425,0.793)	<0.001	<0.001
No	Ref	0.676 (0.466,0.982)	0.040	0.832 (0.563,1.228)	0.354	0.448 (0.277,0.725)	0.001	
Hypertension								
Yes	Ref	0.692 (0.480,0.997)	0.048	0.712 (0.487,1.041)	0.079	0.353 (0.224,0.557)	<0.001	0.069
No	Ref	0.947 (0.703,1.277)	0.722	0.952 (0.706,1.282)	0.744	0.659 (0.482,0.900)	0.009	
AMI								
Yes	Ref	1.186 (0.760,1.852)	0.453	0.794 (0.497,1.271)	0.337	0.823 (0.492,1.378)	0.460	0.670
No	Ref	0.750 (0.566,0.993)	0.045	0.966 (0.721,1.294)	0.818	0.561 (0.394,0.799)	0.001	
HF								
Continued								

(B)								
		Q2		Q3		Q4		
Subgroups	Q1	HR(95%CI)	P value	HR(95%CI)	P value	HR(95%CI)	P value	P for interaction
Yes	Ref	0.713 (0.532,0.955)	0.023	0.854 (0.647,1.126)	0.262	0.601 (0.448,0.805)	<0.001	0.811
No	Ref	1.065 (0.731,1.552)	0.744	0.789 (0.512,1.215)	0.282	0.343 (0.202,0.582)	<0.001	
Stroke								
Yes	Ref	1.063 (0.670,1.686)	0.796	0.975 (0.592,1.608)	0.922	0.453 (0.246,0.834)	0.011	0.657
No	Ref	0.759 (0.581,0.991)	0.043	0.789 (0.607,1.027)	0.078	0.545 (0.412,0.722)	<0.001	
AF								
Yes	Ref	0.750 (0.542,1.036)	0.081	0.718 (0.516,0.993)	0.046	0.439 (0.304,0.632)	<0.001	0.132
No	Ref	0.875 (0.630,1,216)	0.426	0.929 (0.669,1,289)	0.659	0.630 (0.441,0.901)	0.011	
CKD								
Yes	Ref	1.002 (0.676,1.484)	0.994	1.003 (0.665,1.515)	0.987	0.858 (0.562,1.311)	0.479	0.762
No	Ref	0.992 (0.736,1,337)	0,0.959	0.998 (0.746,1.336)	0.990	0.854 (0.610,1.196)	0.358	

Table 3. Subgroup analysis of the TyG-BMI index and one-year all-cause mortality as well as 180-day all-cause mortality in the population with stage 4 CKM syndrome. (A) One-year all-cause mortality rate; (B) 180-day all-cause mortality rate.

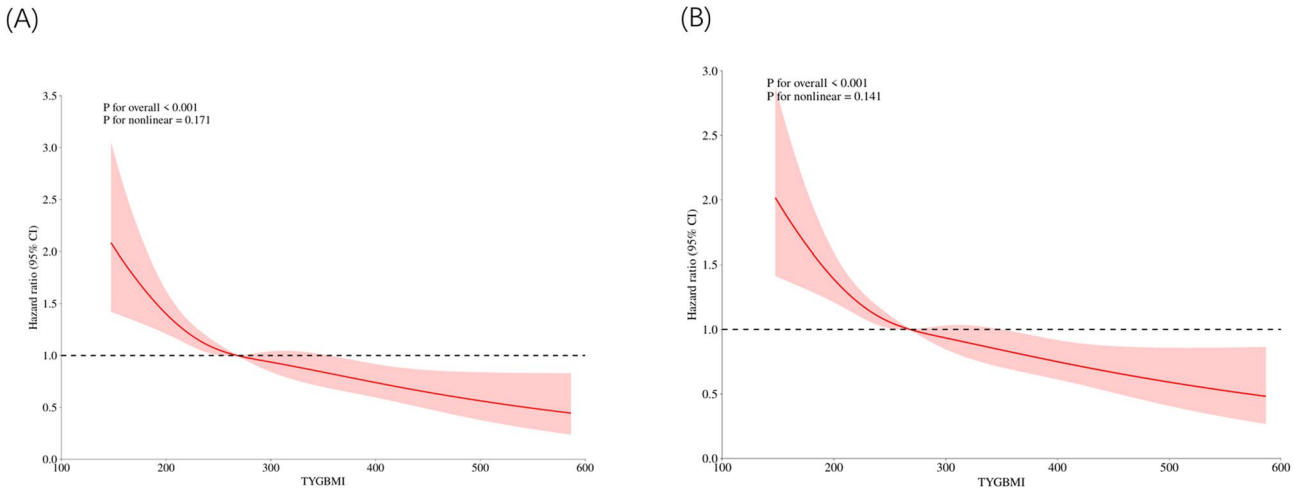

Fig. 3. RCS analysis between the TyG-BMI index and the one-year all-cause mortality rate (**A**) as well as the 180-day all-cause mortality rate (**B**) in the population with stage 4 CKM syndrome. Adjusted according to age, gender, BMI, marital status, hypertension, AMI, HF, stroke, ARF, WBC, RBC, PLT, HGB, RDW, HCT, K^+, CA^{2+}, CL^-, GLU, INR, TG, BUN, and CREA.

this classification revealed similar results (Supplementary Material Table 4). After removing the samples with TyG-BMI index values exceeding 3 SD from the mean, repeating the main analysis still yielded robust results (Supplementary Material Table 5). After adding other covariates such as glucocorticoids, antihypertensive drugs, insulin, and statins and rerunning the main analysis, similar results were obtained (Supplementary Material Table 6). Insulin was used as an instrumental variable, and the causal relationship between TyG - BMI and all - cause mortality was explored through the two - stage residual inclusion (2SRI) method. The results of the instrumental variable analysis of the relationship between TyG - BMI and all - cause mortality indicated that there was a negative correlation between TyG - BMI and the risk of death, and the results were robust (Supplementary Material Table 7). The sensitivity analysis for unmeasured confounding factors further confirmed the reliability of the results (Supplementary Material Fig. 1).

Discussion

In this retrospective study, we demonstrated for the first time a significant negative correlation between the TyG-BMI index and both one year and 180 day all-cause mortality in patients with stage 4 CKM syndrome. This association remained statistically significant even after adjusting for potential confounding factors. Furthermore, our analysis revealed a significant linear relationship between these two variables. Consequently, the TyG-BMI index can serve as an independent risk predictor for critically ill patients with stage 4 CKM and may become an important tool for clinical decision-making.

IR is a multifaceted metabolic state that affects multiple systems, including metabolism, cardiovascular health, and cancer[20,21]. It is known to trigger chronic inflammation and oxidative stress, which in turn, influence other hormones and physiological functions[22]. The TyG-BMI index has been widely recognized as a reliable surrogate marker for IR[12]. Numerous studies have demonstrated that the TyG-BMI index is associated with the incidence and mortality of metabolic syndrome (MS), CVD, and CKD across various cohorts[23–25].

In a study examining the correlation between multiple IR surrogate indices and the 5-year mortality rate in patients with chronic heart failure, it was found that an elevated TyG-BMI index was significantly associated with an increased risk of mortality[26]. Keke Dang et al.[27] reported that in elderly and female patients, higher TyG-BMI indices were linked to a greater incidence of adverse cardiovascular and cerebrovascular events. Another study, which had a median follow-up of 165.4 months and included 355,242 individuals without a history of CVD, found that a higher TyG-BMI was associated with an increased risk of cardiac arrest, with an earlier onset correlating with a higher risk[28].Zixiang Ye et al.[29]highlighted that the TyG index serves as a predictor of both in-hospital and one-year mortality in ICU patients with CAD and CKD. Additionally, during the one-year follow-up, a higher TyG index was associated with a 34.3% increase in the risk of death. Li W et al.[30]were the first to investigate this relationship within the context of CKM and suggested that in the CKM syndrome stages 0–3 population, the TyG-BMI index exhibits a positive linear correlation with an increased incidence of CVD. However, there is currently insufficient data to substantiate the relationship between TyG-BMI and future mortality risk in the CKM syndrome stage 4 population.

Our research found that a higher TyG-BMI index level was significantly associated with a lower mortality rate, presenting a counterintuitive epidemiological conclusion that may be linked to the obesity paradox. In recent years, an increasing number of studies have confirmed the existence of the obesity paradox across various fields. For instance, a study involving 7,619 critically ill patients demonstrated that an increase in BMI was associated with a lower four-year mortality rate[31]. Additionally, research by Lee Y et al.[32]on sepsis supports this perspective, indicating that this conclusion is particularly applicable to elderly sepsis patients, but not to their younger counterparts.

In the domain of cardiovascular diseases, the phenomenon known as the obesity paradox is frequently observed across a range of conditions, including atrial fibrillation, chronic heart failure, acute heart failure, postoperative recovery from valvular disease, and post-transcatheter valve replacement[33–36]. In a similar vein, Drago et al.[37]propose that the association between elevated BMI and a decreased risk of hypoglycemia may play a role in the observed lower mortality rates. Additionally, the obesity paradox is also evident among patients suffering from cachexia related to tumors. Some researchers have argued that the use of BMI as a metric for obesity in cancer patients presents certain limitations, advocating for the adoption of methodologies that can more effectively differentiate abdominal obesity for a more precise evaluation[38].

However, the biological basis of this paradox is multifaceted and warrants further in-depth investigation. Advanced-stage CKM is characterized by accelerated catabolism and increased energy demands. In particular, patients with advanced CKM complicated by HF are unable to normally intake sufficient calories and nutrients due to factors such as gastrointestinal dysfunction, leading to relative nutritional deficiency.Obese CKM patients possess substantial lipid reserves that can serve as an energy buffer during metabolic stress. These reserves can delay muscle wasting and the occurrence of cachexia by providing substrates for β-oxidation, thereby maintaining cardiopulmonary function[39]. Additionally, obesity is associated with reduced activity of the ubiquitin-proteasome and autophagy-lysosome pathways, which are key drivers of muscle atrophy in critically ill CKM patients[40]. This preservation of muscle mass may enhance the physical resilience of patients with stage 4 CKM.Although obesity is associated with chronic low-grade inflammation, adipose tissue may exert immunomodulatory effects under acute stress conditions. Cytokines secreted by adipose tissue, such as adiponectin, possess anti-inflammatory properties that can alleviate systemic inflammation and oxidative stress in advanced CKM syndrome. Adiponectin can enhance insulin sensitivity, improve endothelial dysfunction, and inhibit pro-inflammatory pathways (such as the activation of nuclear factor κB (NF-κB)), potentially counteracting the hyperinflammatory state observed in patients with stage 4 CKM[41].In patients with advanced CKM, persistent inflammation may induce immune tolerance, reducing tissue damage caused by excessive immune responses, and adipose tissue may shift from a pro-inflammatory phenotype to an anti-inflammatory phenotype. Moreover, adipose tissue sequesters circulating lipopolysaccharides (LPS) through lipoprotein binding, reducing endotoxin-induced organ damage and improving the prognosis of sepsis-related complications, which are prevalent in this patient population[42,43].Obesity is also associated with adaptive hemodynamic and hormonal responses that may confer survival advantages. Adipose tissue secretes soluble tumor necrosis factor-α (TNF-α) receptors, which can neutralize the pathophysiological effects of TNF-α and provide potential cardioprotective benefits[44]. In patients with advanced CKM often complicated by acute or chronic HF, the circulating levels of atrial natriuretic peptide (ANP) in overweight or obese individuals are usually significantly lower[45]. In such patients, the activity of the sympathetic nervous system and the responsiveness of the renin-angiotensin system (RAS) are typically attenuated, manifested as reduced neurohormonal activation. These patients often have a higher baseline arterial pressure, which may be associated with an improved prognosis in patients with advanced CKM and enhanced tolerance to cardioprotective drugs (such as β-blockers, angiotensin-converting enzyme inhibitors/angiotensin II receptor blockers). At the same time, as a reservoir for fat-soluble drugs, adipose tissue may prolong the half-life of drugs, maintain a steady-state concentration, and can metabolize glucocorticoids, reducing systemic toxicity. Additionally, obese patients have a higher blood volume, and in patients with stage 4b CKM who have poor cardiac function, they may better tolerate the reduction of cardiac preload, delaying hypotension and low organ perfusion.Obese patients who are able to survive to the advanced stage of CKM may have unrecognized genetic or phenotypic advantages (such as anti-inflammatory gene polymorphisms), causing a certain degree of survivor bias. Overall, these mechanisms are likely to play a protective pathophysiological role in obese CKM patients. Meanwhile, it is necessary to be wary of the limitations of BMI[46].

In the subgroup analysis, our study identified a significant interaction between ARF and the TyG - BMI index among CKM patients, which exerted a notable impact on patient prognosis. Specifically, compared to stage 4a patients (without renal failure), stage 4b patients (with renal failure) presented a higher TyG - BMI index and faced a greater risk of mortality. This suggests that the metabolic derangements induced by acute renal failure overshadow the protective effect of obesity. Such a phenomenon might be attributed to a combination of factors, including oxidative stress, the accumulation of uremic toxins, and the acceleration of atherosclerosis.ARF compromises glomerular filtration and tubular function, thereby giving rise to dyslipidemia. This is characterized by elevated TG levels and reduced high - density lipoprotein (HDL) levels, disrupting the equilibrium between lipid storage and utilization[47]. As a result, ectopic lipid deposition occurs in non - adipose tissues like the kidneys and liver. This lipotoxicity further exacerbates insulin resistance and mitochondrial dysfunction. Consequently, the production of adenosine triphosphate (ATP) is diminished, and cell damage is aggravated. ARF downregulates peroxisome proliferator - activated receptor α (PPARα) and its co - activator PGC − 1α, which are crucial regulators of fatty acid oxidation and mitochondrial biogenesis. This downregulation impairs the capacity for lipid catabolism, leading to intracellular lipid accumulation and oxidative stress[48]. Obesity is inherently associated with low - grade chronic inflammation, as evidenced by elevated levels of cytokines such as tumor necrosis factor - α (TNF - α) and interleukin − 6 (IL − 6). ARF further intensifies the systemic inflammatory response by activating the NLRP3 inflammasome and releasing damage - associated molecular patterns (DAMPs), thereby triggering an "inflammatory storm"[49]. In this process, the anti - inflammatory effects of adipose tissue, such as adiponectin secretion, may be overwhelmed[50].Moreover, the elevated blood urea nitrogen and acidosis induced by ARF can inhibit the functions of macrophages and T cells. This impairs the ability of obese patients to maintain homeostasis through immunomodulation. Additionally, oliguria or anuria caused by ARF can rapidly lead to fluid retention. This increases the cardiac preload, potentially triggering acute pulmonary edema and cardiogenic shock[51]. In obese patients, the initially beneficial higher blood volume may transform into a detrimental burden.Clinically, these findings underscore the importance of proactive management of acute renal failure in stage 4 CKM patients. This includes the implementation of early renal replacement therapy and targeted treatments aimed at restoring lipid balance, such as the use of fibrates or ω − 3 fatty acids[52].

From a clinical perspective, in advanced CKM, TyG-BMI should not be regarded as a direct therapeutic target but rather as a multi-faceted biomarker that reflects the complex interplay among metabolic disorders, nutritional status, and disease severity. It integrates indicators such as insulin resistance, lipid metabolism, and body mass index, yet it lacks specificity for body composition.For example, in patients with stage 4 CKM, a low TyG-BMI may not only imply a reduction in insulin resistance but also potentially indicate underlying energy depletion, muscle loss, and malnutrition. On the other hand, a high TyG-BMI may suggest that energy reserves are maintained, but there is also persistent insulin resistance. Patients in the lowest quartile of TyG-BMI are at a higher risk and are likely to suffer from cachexia or severe metabolic stress. Therefore, there is an urgent need to assess their muscle mass (e.g., through bioelectrical impedance analysis) and inflammatory markers. On the contrary, for those patients with a high TyG-BMI, a careful assessment of their body composition is required to distinguish between protective adipose tissue and harmful visceral fat.For patients with a low TyG-BMI, the focus should be on comprehensive nutritional support, anti-catabolic therapies, and anti-inflammatory strategies, rather than directly intervening on the TyG-BMI value. In contrast, for patients with a high TyG-BMI, clinicians should handle the issue of residual insulin resistance with caution and avoid interventions that may exacerbate malnutrition.Longitudinal monitoring of TyG-BMI, combined with functional status indicators such as gait speed and grip strength, helps to differentiate between progressive cachexia and stable metabolic adaptation. In addition, integrating TyG-BMI with other biomarkers (such as albumin, prealbumin, and C-reactive protein) can provide a more comprehensive risk assessment, enabling personalized management of patients.Furthermore, correcting metabolic acidosis and other metabolic abnormalities commonly seen in CKM helps to improve the overall metabolic state and may potentially increase the TyG-BMI.Besides, patients are recommended to receive weight loss advice mainly focusing on increasing physical activity, especially through structured exercise programs aimed at increasing Cardiorespiratory fitness (CRF).In a study of obese individuals, it was found that compared with the control group without weight loss, the mortality rate of those who intentionally lost weight decreased by 24%, while the mortality rate of those with unintentional weight loss was 31% higher[53]. The improvement in the outcomes of those who intentionally lost weight is likely related to the increase in CRF.It is worth noting that among the patient populations with HF, CVD, and AF, there seems to be an obesity paradox among those with poor physical fitness. That is, obese individuals with poor physical fitness, especially those with Class I obesity (BMI: 30-34.99), seem to have a better prognosis[54–56]. However, the group of obese individuals with good physical fitness seems to overcome this paradox and has a good prognosis regardless of their weight, which suggests that obese individuals with poor physical fitness may benefit more from improving CRF than from simply losing weight[57].Nevertheless, these findings should not deny the potential benefits of weight loss. Instead, structured exercise programs aimed at increasing CRF are more recommended to promote weight loss. Many studies have shown that purposeful weight loss is associated with improved prognosis.Our study found that a TyG-BMI threshold below approximately 267.95 (the critical value of Q2) may indicate an increased risk of death. Clinicians can use this threshold to trigger early interventions, such as initiating evidence-based medical therapies known to improve the outcomes of CKM syndrome (such as SGLT2 inhibitors and GLP-1 receptor agonists).In addition, for patients close to this critical value, lifestyle improvements (such as structured exercise programs and dietary adjustments) can be emphasized to prevent a further decrease in TyG-BMI. Timely identification and management of these factors can improve the survival rate of patients with stage 4 CKM.

However, this study has several limitations. First, it is a single-center, retrospective study with a relatively short follow-up period, which limits the ability to establish clear causal relationships. Second, although

we included a wide range of covariates and potential confounding factors in the analysis, there may still be uncontrolled residual or unmeasured confounding factors. For example, due to a large amount of missing data, we did not consider variables such as estimated glomerular filtration rate (eGFR), thyroid-stimulating hormone (TSH), left ventricular ejection fraction (LVEF), and socioeconomic status. Also, due to database limitations, we could not include aspects such as nutritional status, muscle mass, and unmeasured aspects of treatment (e.g., dosing, adherence, or new therapies like SGLT2 inhibitors/GLP-1 agonists). This may lead to potential biases in the research results. Although this study included different patients, the age distribution may be skewed, with a higher proportion of elderly patients, which may cause the study results to be more representative of the elderly population, raising questions about their applicability to younger stage 4 CKM patients. In terms of gender, the higher proportion of males in the study cohort may affect the assessment of the impact of certain gender-specific factors on the outcomes. Regarding ethnicity, although different ethnic groups were included, the differences in sample sizes among these groups may affect the stability and generalizability of the study results. These demographic distribution characteristics may influence the generalizability of the study findings, limiting the applicability of the results to patient populations with different age, gender, and ethnic compositions. Additionally, this study only considered the prognostic value of the baseline TyG-BMI index, neglecting any changes in dynamic factors such as weight or metabolic status during hospitalization and follow-up.

In terms of the generalizability of the results, they are currently derived only from a specific patient population in the MIMIC-IV database. There are differences in medical standards, living environments, and disease spectra across different regions, which may lead to variations in the clinical characteristics, treatment methods, and the relationship between the TyG-BMI index and mortality among stage 4 CKM patients. For example, in areas with scarce medical resources, patient treatment adherence and prognosis may differ from the cohort in this study. Additionally, the genetic backgrounds and lifestyles of different racial and ethnic groups may also affect insulin resistance levels and the association between the TyG-BMI index and mortality. Therefore, further validation is needed in populations from different regions, races, and medical environments to comprehensively assess the external validity of the research findings. Future studies should strive to address these issues as thoroughly as possible by establishing large-scale, multi-center, prospective research to ensure that these results are applicable to a broader range of stage 4 CKM patients.

Conclusion

This study is the first to investigate the predictive capability of the TyG-BMI index for one-year mortality in patients with stage 4 CKM syndrome patients. Our findings reveal a negative correlation between the TyG-BMI index and one-year mortality in this population, demonstrating a linear association. Therefore, the TyG-BMI index may serve as a significant indicator for risk stratification and prognosis prediction in patients with stage 4 CKM syndrome patients.

Data availability

The datasets analyzed in this study are available from the corresponding author. However, due to the nature of the data from the MIMIC-IV database, access is subject to the database's terms and conditions. Users need to apply for access through the official MIMIC-IV database channels. Once access is granted, relevant data subsets used in this research can be requested from the corresponding author. The corresponding author will ensure that data sharing adheres to all ethical and legal requirements, and will assist in providing necessary documentation and guidance for data retrieval.

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Author contributions

WP, TFJ and JW were responsible for the study concept and design. WP and TFJ extracted and collated the data. WP and BTH conducted the statistical analysis and interpretation. WP, JY, LL drafted the manuscript and performed the literature search. WP, TFJ and BTH contributed to the manuscript revision. JW was responsible for supervising the study and providing critical comments. All authors reviewed and approved the submitted manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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