Nutrition & Metabolism

RESEARCH

Open Access

Triglyceride-glucose index predicts all-cause mortality, but not cardiovascular mortality, in rural Northeast Chinese patients with metabolic syndrome: a community-based retrospective cohort study

Shasha Yu[1†], Qiyu Li[1†], Hongmei Yang[1], Xiaofan Guo[1], GuangXiao Li[2] and Yingxian Sun[1*]

Abstract

Background Metabolic syndrome (MetS) includes a group of metabolic irregularities, including insulin resistance (IR), atherogenic dyslipidemia, central obesity, and hypertension. Consistent evidence supports IR and ongoing low-grade inflammation as the main contributors to MetS pathogenesis. However, the association between the triglyceride-glucose (TyG) index and mortality in people with MetS remains uncertain. The objective of this study was to examine the correlation between the baseline TyG index and all-cause and cardiovascular (CV) mortality in rural Northeast Chinese individuals with MetS.

Methods For the Northeast China Rural Cardiovascular Health Study, 3918 participants (mean age, 55 ± 10; 62.4% women) with MetS at baseline were enrolled in 2012–2013 and followed up from 2015 to 2017. The TyG index was calculated using the equation TyG index = ln [fasting TG (mg/dL) × fasting glucose (mg/dL)/2] and subdivided into tertiles [Q1(< 8.92); Q2 (8.92–9.36); Q3 (≥ 9.36)]. Multivariate Cox proportional hazards models were developed to examine the correlations between mortality and the baseline TyG index.

Results During a median of 4.66 years of follow-up, 196 (5.0%) all-cause deaths and 108 (2.8%) CV disease-related deaths occurred. The incidence of all-cause mortality was significantly different among TyG index tertiles of the overall population ($P = 0.045$). Kaplan–Meier analysis demonstrated a significantly increased risk of all-cause mortality in rural Chinese patients with a higher TyG index (log-rank $P < 0.05$). After adjusting for possible confounders, Cox proportional hazard analysis revealed that the TyG index could effectively predict all-cause mortality (HR for the third vs. first tertile of TyG was 1.441 [95% confidence interval, 1.009–2.059]), but not CV mortality, in rural Chinese patients with MetS.

Conclusions The TyG index is an effective predictor of all-cause mortality in rural Chinese patients with MetS. This indicates that the TyG index may be useful for identifying rural Chinese individuals with MetS at a high risk of death.

[†]Shasha Yu and Qiyu Li contributed equally to this work.

*Correspondence:
Yingxian Sun
sunyingxiancmu1h@163.com

Full list of author information is available at the end of the article

Keywords Metabolic syndrome, Triglyceride-glucose index, Cardiovascular mortality, All-cause mortality, Rural China

Introduction

Metabolic syndrome (MetS) includes a cluster of conditions associated with metabolic dysregulation, such as insulin resistance (IR), atherogenic dyslipidemia, central obesity, and hypertension. Cumulative evidence has confirmed that IR and persistent low-grade inflammation are the primary pathogenic factors of MetS [1]. SPECT-China, a population-based cross-sectional survey of Chinese individuals ≥ 18 years of age, reveals a 22.0% age-standardized prevalence of MetS in East China [2]. Similarly, our previous study found that MetS has gradually become more prevalent among participants from rural China (39.0%) [3]. If left untreated, MetS considerably increases morbidity and mortality [1]. It is thus crucial to investigate an effective predictor of mortality in patients with MetS to reduce the substantial disease burden.

Recently, the triglyceride-glucose (TyG) index has garnered increasing global attention, as it is associated with all-cause and cardiovascular (CV) mortality in the general population [4]. Similarly, Liao et al. observed a strong association between the TyG index and an increase in all-cause mortality in critically ill patients [5]. A U-shaped association was further observed between the TyG index and all-cause mortality in American patients with cardiovascular diseases (CVDs) and diabetes or prediabetes [6]. Multiple studies have also comprehensively investigated the predictive value of the TyG index as a biomarker for IR [7]. As the underlying mechanism of MetS is IR, it can also be diagnosed by measuring the TyG index [8]. However, whether the TyG index can predict mortality among patients with MetS remains unknown.

As previously mentioned, economic development has led to increasing trends in metabolic disorders in rural Chinese areas. The TyG index is affordable and readily available, making it a suitable and widely used index to predict mortality among patients with MetS in rural areas. The aim of this study was to evaluate the impact of the baseline TyG index on all-cause and CV mortality in participants with MetS from rural areas of China.

Methods

Study population

A community-based retrospective cohort study was carried out in rural Northeast China, with the study details previously described [3]. This research was granted approval by China Medical University's Ethics Committee (Shenyang, China AF-SDP-07-1, 0–01). Baseline information was acquired from the 2012–2013 survey, and 11,956 individuals were enrolled. The study cohort was subjected to follow-up from 2015 to 2017, with a median duration of 4.66 years. The comprehensive procedure for participant inclusion is presented in Fig. 1, resulting in data analysis for 3918 participants.

Study variables

The participants' heights and weights were recorded while wearing casual clothing and not wearing shoes. At the umbilicus, the waist circumference was measured using non-elastic tape. The participants' blood pressure was measured three times using an electronic, standardized, automated manometer (HEM-907; Omron, Tokyo, Japan) after at least 5 min of sitting still. Participants' blood was extracted after a fasting period of at least 12 h, and enzymatic methods were used to identify the fasting plasma glucose (FPG), low-density lipoprotein cholesterol (LDL-C), and other biochemical indicators that are frequently evaluated.

At baseline, a standardized questionnaire was used in an interview to obtain information on medical histories, lifestyle factors, and demographic features. Additionally, current alcohol and tobacco use was defined. The total duration of sleeping (in hours) across the span of 24 h was utilized for calculating the duration of sleep. An individual's educational situation was ascertained according to the completion of elementary, middle, or high school. The family's annual income was categorized as follows: ≤5000 CNY (788 dollars), 5000–20,000 CNY (788–3152 dollars), or >20,000 CNY (3152 dollars). The physical activity of the participants (Fig. 2), encompassing both work-related and recreational pursuits, was evaluated and divided into three categories [3].

Definition

The TyG index was calculated using the following equation: ln [fasting triglycerides (mg/dL) × fasting glucose (mg/dL)/2] [9]. Body mass index (BMI) was determine using the following equation: BMI = $\frac{weight(kg)}{(height)^2(m)}$. Figure 3 provides the definition of the ATPIII-modified criteria [10].

Statistical analyses

The individuals were divided into three groups based on their TyG index levels, with each group representing one-third of the total participants, as follows: tertile 1 (n=1309, TyG index<8.92), tertile 2 (n=1299, 8.92≤TyG index<8.92–9.36), and tertile 3 (n=1310, TyG index≥9.36), with the depicted characteristics. Categorical variables have been quantified using numerical values (n) and percentages (%) and were evaluated using the chi-squared test. Continuous variables with a normal distribution are expressed as the mean±standard deviation; non-normal distributions are represented as the

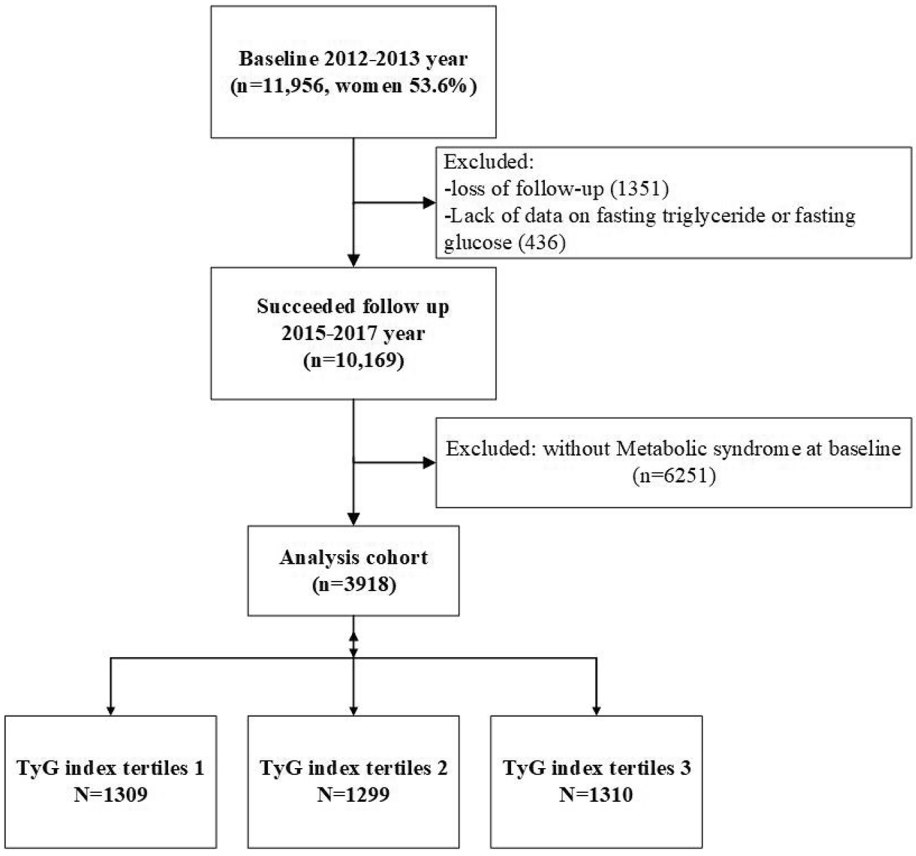

Fig. 1 Process for the inclusion of trial patients. TyG index, triglyceride-glucose index

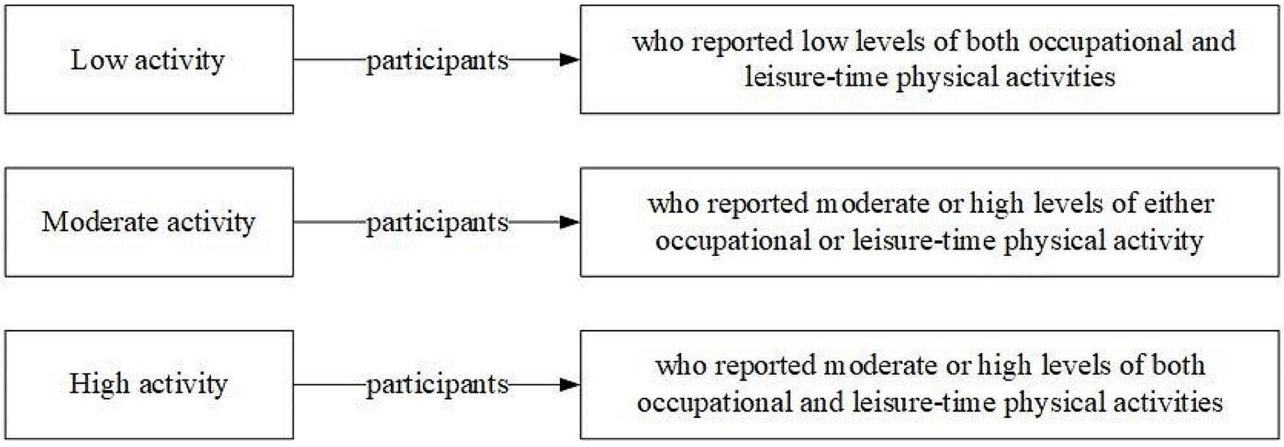

Fig. 2 Categories of physical activity

median (interquartile range). Data were analyzed using one-way analysis of variance for a normal distribution and the Kruskal–Wallis test for a non-normal distribution. We investigated the precise correlation between the TyG index and mortality from all causes and CVDs in people with MetS using multivariate Cox proportional hazards models. Three sets of models were constructed in this study. Model 1 included only the TyG index, whereas Model 2 incorporated demographic attributes such as age, sex, and race. Model 3 further adjusted for education, current smoking and drinking habits, annual income, sleep duration, physical activity, and cardiovascular history. A stratified analysis was conducted to examine the impact of putative effect modifiers, including age, sex, BMI, and current smoking and drinking status, on relevant variables. The statistical analyses were

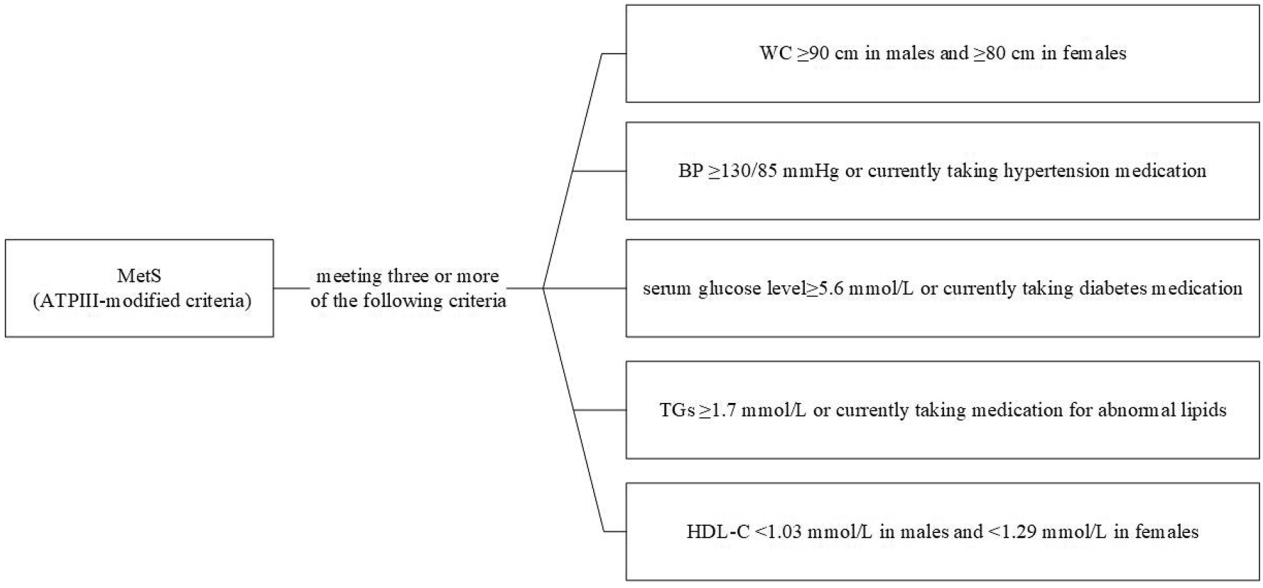

Fig. 3 Definition of metabolic syndrome and metabolic disorders

conducted using R software (version 4.2.1; R Foundation for Statistical Computing, Vienna, Austria), and statistical significance was defined as $P<0.05$.

Results

Population characteristics stratified using the TyG index

As presented in Table 1, baseline participant characteristics were stratified using TyG index tertiles (Q) as follows: Q1, <8.92; Q2, 8.92–9.36, and Q3≥9.36. The mean TyG index levels in these tertiles were 8.54±0.29, 9.13±0.122, and 9.87±0.48, respectively. The participants with higher TyG index values were generally male, older, and current smokers and drinkers, had a longer sleep duration, and exhibited a higher prevalence of CV comorbidities. Additionally, they experienced a higher incidence of all-cause mortality than those with lower TyG index values (4.1% vs. 4.7% vs. 6.2%, $P=0.045$). Moreover, the higher TyG index group exhibited higher levels of HbA1C, LDL-C, TC, TG, uric acid, FPG, AST, and ALT, along with lower eGFR and HDL-C levels (Table 2).

Associations between the TyG index and all-cause and CV mortality

Cox proportional hazard analysis revealed a significant association between the TyG index and all-cause mortality, but not CV mortality, in both crude and adjusted models [crude: all-cause mortality HR, 1.303 (95% CI, 1.061–1.600), $P=0.012$; CV mortality HR, 1.224 (95% CI, 0.923–1.623), $P=0.160$]; Model 2: all-cause mortality HR, 1.330 (95% CI, 1.075–1.646), $P=0.009$; CV mortality HR, 1.249 (95% CI, 0.931–1.674), $P=0.138$; Model 3: all-cause mortality HR, 1.288 (1.033–1.605), $P=0.025$; CV mortality HR, 1.194 (95% CI, 0.879–1.622), $P=0.257$]. In both the crude and adjusted models, upward trends were observed between the TyG index and all-cause mortality (Table 3, both $P<0.05$). The participants in the Q3 TyG index tertile had a significantly higher incidence of all-cause mortality than those in the Q1 and Q2 tertiles [HR, 1.441 (95% CI, 1.009–2.059), $P=0.016$].

Subgroup analysis of the association between the TyG index and all-cause and CV mortality

Stratification was performed based on age, sex, BMI, and current smoking and drinking status to evaluate the impact of the TyG index on the primary endpoints (Fig. 4). Except for the age subgroup (age subgroup: all-cause mortality, P for interaction<0.001), no significant interactions were observed in most subgroups. The TyG index was associated with all-cause mortality in patients<65 years of age [all-cause mortality: HR, 1.374 (95% CI, 1.036–1.823)]; however, this was not the case for participants≥65 years of age [all-cause mortality: HR, 1.121 (95%, CI 0.782–1.606)].

Discussion

In this study, a substantial relationship between the TyG index and all-cause mortality, but not CV mortality, was found in a rural Chinese population with MetS. Moreover, a significant interaction effect was identified between age and the TyG index, suggesting that the correlation between TyG levels and mortality was particularly pronounced among patients who were younger in age. Recently, the incidence of MetS has considerably increased in rural Chinese areas. A meta-analysis indicated a 24.5% prevalence of MetS among individuals 15 years and older in mainland China, with 19.2% residing in

Table 1 Baseline characteristics of study participants by Triglyceride glucose Index (TyG) index tertile

Variables	Tertiles of TyG index				
	overall	Q 1(< 8.92)	Q 2 (8.92–9.36)	Q 3(≥ 9.36)	*P* value
N	3918	1309	1299	1310	
Gender (female)		935(71.4)	779(60.0)	730(55.7)	< 0.001
Age (years)	55.44 ± 10.18	54.77 ± 10.44	56.02 ± 10.26	55.53 ± 9.80	< 0.001
Current smoking (yes)	1170(29.9)	299(22.8)	425(32.7)	446(34.0)	< 0.001
Current drinking (No)	706(18.0)	170(13.0)	233(17.9)	303(23.1)	< 0.001
Ethnicity[a](Han)	3705(94.6)	1235(94.3)	1243(95.7)	1227(93.7)	0.068
Education status					0.126
Primary school or below	2174(55.5)	692(52.9)	752(57.9)	730(55.7)	
Middle school	1366(34.9)	480(36.7)	434(33.4)	452(34.5)	
High school or above	378(9.6)	137(10.5)	113(8.7)	128(9.8)	
Annual income (CNY/year)					0.708
≤ 5000	481(12.3)	154(11.8)	154(11.9)	173(13.2)	
5000–20,000	2134(54.5)	709(54.2)	710(54.7)	715(54.6)	
> 20,000	1301(33.2)	445(34.0)	435(33.5)	421(32.2)	
Sleep duration (h/d)					0.017
≤7	1968(50.3)	657(50.2)	676(52.2)	635(48.5)	
7–8	1060(27.1)	373(28.5)	349(26.9)	338(25.8)	
8–9	558(14.3)	189(14.4)	163(12.6)	206(15.7)	
>9	326(8.3)	89(6.8)	108(8.3)	129(9.9)	
Physical activity					0.276
Low	1680(43.2)	530(40.8)	574(44.4)	576(44.4)	
Moderate	712(18.3)	244(18.8)	228(17.6)	240(18.5)	
High	1494(38.4)	524(40.4)	490(37.9)	480(37.0)	
Pulse (times/min)	81 ± 14	79 ± 13	80 ± 14	83 ± 14	< 0.001
BMI (kg/m^2)	26.89 ± 3.39	26.84 ± 3.39	26.65 ± 3.36	27.19 ± 3.41	< 0.001
WC (cm)	88.54 ± 8.67	88.38 ± 8.39	87.71 ± 9.17	89.52 ± 8.35	< 0.001
Height (m)	159.95 ± 8.36	159.28 ± 7.94	160.09 ± 8.30	160.48 ± 8.78	0.001
SBP (mmHg)	151.10 ± 22.71	150.37 ± 22.27	150.06 ± 22.86	152.87 ± 22.92	0.003
DBP (mmHg)	86.26 ± 11.53	85.52 ± 11.21	85.99 ± 11.38	87.25 ± 11.93	< 0.001
Cardiovascular Comorbidities (Yes)	448(11.4)	138(10.5)	129(9.9)	181(13.8)	0.004
Out comes					
All-cause mortality, n (%)	196(5.0)	54(4.1)	61(4.7)	81(6.2)	0.045
Cardiovascular mortality, n (%)	108(2.8)	29(2.2)	37(2.8)	42(3.2)	0.293

[a] others including some ethnic minorities in China, such as Mongol and Manchu. Abbreviations: CNY China Yuan (1CNY = 0.161 USD), BMI body mass index, WC waist circumference, SBP Systolic Blood pressure, DBP diastolic blood pressure, FPG fasting plasma glucose, HDL-C high-density lipoprotein, LDL-C low-density lipoprotein cholesterol

Table 2 Baseline levels of laboratory characteristics according to the Triglyceride glucose Index (TyG) index quartiles

Variables	Tertiles of TyG index				
	overall	Q 1(< 8.92)	Q 2 (8.92–9.36)	Q 3(≥ 9.36)	*P* value
HbA1C(%)	5.67 ± 1.16	5.39 ± 0.69	5.49 ± 0.82	6.12 ± 1.56	< 0.001
eGFR(ml/min/1.73m^2)	90.23 ± 16.02	91.57 ± 15.37	89.41 ± 16.54	89.70 ± 16.07	0.001
LDL-C(mmol/L)	3.18 ± 0.31	2.98 ± 0.76	3.27 ± 0.88	3.29 ± 0.99	< 0.001
HDL-C (mmol/L)	1.25 ± 0.31	1.31 ± 0.34	1.24 ± 0.29	1.19 ± 0.28	< 0.001
TC (mmol/L)	5.49 ± 1.18	5.06 ± 0.99	5.51 ± 1.06	5.92 ± 1.30	< 0.001
TG(mmol/L)	2.33 ± 1.92	1.15 ± 0.33	1.98 ± 0.36	3.85 ± 2.63	< 0.001
Uric acid(umol/L)	306.22 ± 87.99	282.37 ± 77.61	310.59 ± 87.49	324.71 ± 93.14	< 0.001
FPG (mmol/L)	6.50 ± 2.07	5.92 ± 0.88	6.04 ± 1.14	7.54 ± 3.03	< 0.001
BUN(mmol/L)	5.55 ± 2.48	5.64 ± 3.06	5.53 ± 2.08	5.47 ± 2.18	0.222
AST (IU/L)	22.46 ± 11.24	21.33 ± 9.96	22.38 ± 9.59	23.68 ± 13.60	< 0.001
ALT(IU/L)	25.12 ± 17.51	21.85 ± 14.98	25.16 ± 16.36	28.36 ± 20.17	< 0.001

Date are presented as mean (SD) or n (%);

Table 3 HRs (95% CIs) for mortality according to the triglyceride glucose index (TyG) index tertiles

	Tertiles of TyG index			
	Q 1(< 8.92)	**Q 2 (8.92–9.36)**	**Q 3(≥ 9.36)**	***P*trend**
All-cause mortality				
Number of deaths	54	61	81	
Model 1				
HR(95%CI)	1	1.147(0.795,1.654)	**1.496(1.060,2.111)**	**0.020**
P-value		0.464	**0.022**	
Model 2				
HR(95%CI)	1	1.036(0.718,1.495)	**1.498(1.061,2.115)**	**0.018**
P-value		0.851	**0.021**	
Model 3				
HR(95%CI)	1	1.100(0.758,1.599)	**1.441(1.009,2.059)**	**0.016**
P-value		0.615	**0.045**	
CVD mortality				
Number of deaths	29	37	42	
Model 1				
HR(95%CI)	1	1.296(0.797,2.106)	1.446(0.901,2.321)	0.129
P-value		0.297	0.127	
Model 2				
HR(95%CI)	1	1.148(0.706,1.868)	1.455(0.905,2.337)	0.116
P-value		0.578	0.121	
Model 3				
HR(95%CI)	1	1.277(0.772,2.113)	1.403(0.851,2.313)	0.108
P-value		0.340	0.184	

Model 1: Non-adjusted

Model 2: Adjusted for age, race and gender

Model 3: Adjusted for age, gender, race, BMI, SBP, DBP, current smoking and drinking, education, annual income, sleep duration, physical activity, cardiovascular history

HR: Hazard ratio; CI: Confidence interval

rural areas [11]. Our previous study held in rural Northeast China revealed a cumulative incidence of newly diagnosed MetS at 24.0% [12]. Given that metabolic disorders often increase insidiously, all-cause and CV mortalities increase at the time of detection in this population [13]. Hence, proactive strategies and tasks should be undertaken to prevent risk factors such as hypertension, hyperlipidemia, elevated blood glucose, and obesity, along with effective measures to predict mortality among patients with MetS. IR is a crucial pathological factor in MetS, contributing to CVDs and poor clinical outcomes in various ways via mechanisms such as endothelial dysfunction, low-level inflammation, and disruptions in systemic glucose–lipid metabolism [14]. Although various indicators are used to measure IR, including the hyperinsulinemic euglycemic (HIEG) clamp test, homeostatic model assessment for insulin resistance (HOMA-IR), and quantitative insulin sensitivity check index, most of these indicators are time-consuming and expensive to determine, limiting their use in rural areas. Consequently, the TyG index has gradually gained attention in recent years owing to its cost-effectiveness compared to other parameters. In comparison to the gold standard (HIEG clamp test), Won et al. demonstrated that the TyG index has high sensitivity (96.5%) and specificity (85.0%) for IR detection [15]. Furthermore, when compared to the HOMA-IR, the TyG index was confirmed to perform better in assessing IR [16]. The precise mechanism explaining the connection between the TyG index and mortality is still not understood. Owing to the close relationship between the TyG index and IR, possible explanations could be related to IR-induced pathological processes. An imbalance in glucose metabolism may also be induced by IR, contributing to hyperglycemia, which, consequently, triggers inflammation and oxidative stress. Sasaki et al. found that oxidative stress and inflammation are effective predictors of mortality in patients undergoing hemodialysis [17]. Additionally, IR plays an important role in hyperlipidemia, which is a leading cause of CVDs, resulting in high mortality [18].

A correlation between the TyG index and increased all-cause mortality among rural Chinese individuals with MetS was confirmed for the first time in our study. The TyG index exhibits a notable correlation with an elevated susceptibility to metabolic diseases, such as hypertension [19, 20], diabetes [21], hyperuricemia [22], and MetS. Additionally, it is significantly associated with an increasing risk of various CVDs, including arterial stiffness, stroke, carotid atherosclerosis, myocardial infarction coronary artery disease, and peripheral artery disease

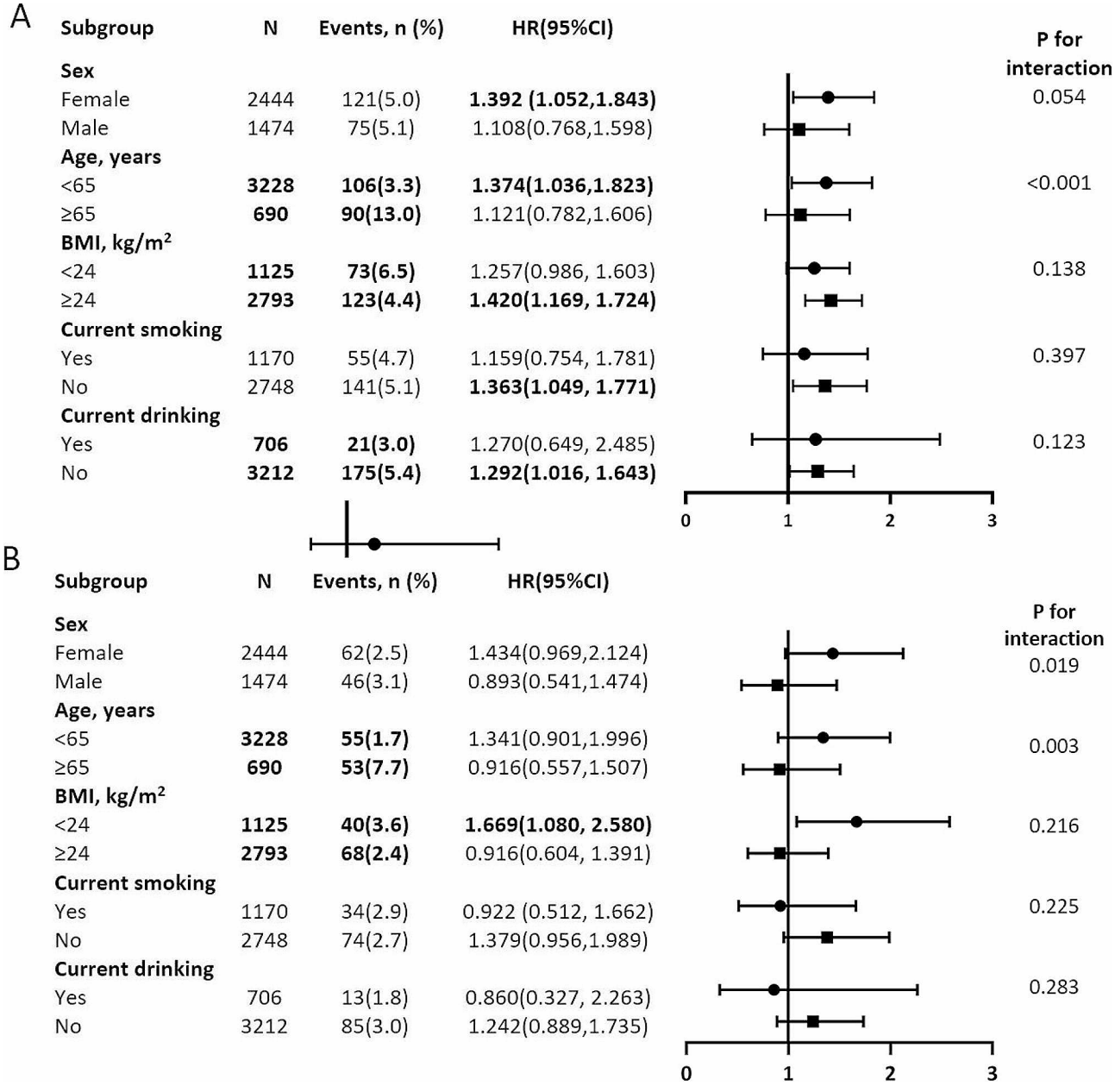

Fig. 4 Subgroup analysis of the association between Triglyceride glucose Index (TyG) index and all-cause mortality (**A**), cardiovascular disease (CV) mortality (**B**) among rural Chinese with Metabolic syndrome (MetS). Each subgroup analysis is adjusted if not stratified for age, gender, race, BMI, SBP, DBP, current smoking and drinking, education, annual income, sleep duration, physical activity, cardiovascular history

[23–26]. Despite its effectiveness in predicting CVDs, the association between TyG and mortality remains inconsistent. A recent systematic review and meta-analysis, composed of 12 cohort studies with 6,354,990 participants, found no correlation between the TyG index and mortality in the overall population, including both cardiovascular and all-cause mortality [27]. Moreover, the correlation between TyG and mortality lost significance after adjusting for age, BMI, blood pressure, and smoking status in one study, whereas another study claimed a positive correlation [28, 29]. In contrast to the uncertain relationship between TyG and mortality in the general population, studies focusing on specific diseases provide a consistent conclusion. Shen et al. found that the TyG index is a predictive measure for the probability of death from any cause in older adults with acute coronary syndrome who also have diabetes [30]. Similar to that in older and middle-aged patients with type 2 diabetes, the TyG index may predict the likelihood of CVD-related mortality or death from any cause [31]. In participants with CVDs, the TyG index exhibited a U-shaped association with the risk of all-cause mortality [32]. Zhou et al. discovered a strong

correlation between the TyG index and the mortality risk in individuals with chronic heart failure [33]. One reason for the discrepancy in the association between TyG and mortality could be the insufficient follow-up time. Furthermore, baseline accompanying diseases may influence the relationship between TyG and mortality.

One interesting finding in the present study was that the TyG index, a well-known parameter representing IR, was not significantly associated with cardiovascular mortality among rural Chinese individuals with MetS. The possible reasons for this contradiction might be as follows. First, the TyG index was first implemented in 2008 with the rationale that IR is frequently the reason for elevated TG and glucose levels in healthy individuals [9]. Not all studies found significant associations between TyG and CVD, especially among those accompanied by chronic diseases, such as diabetes and dyslipidemia [34, 35]. Moreover, the effect of triglycerides or glucose on cardiovascular events could be eliminated by antihyperlipidemic treatment and hypoglycemic drugs with CVDs [32]. The application of the TyG index for cardiovascular mortality can be also affected by hyperlipidemia and diabetes [9]. To justify the value of the TyG index as a biomarker, hypertriglyceridemia and glucose metabolic disorder should be well controlled. However, in the present study, we intended to estimate this relationship in Chinese patients with MetS, as our previous data indicated that high TG levels (32.1%) and increased fasting glucose (47.1%) was prevalent in rural Northeast Chinese individuals [12]. However, despite its high prevalence, its treatment and control rates are obviously low. Owing to the combined effect of these factors, it was not possible to investigate causation when applying the TyG index to these patients. Second, cardiovascular mortality was age-specific. Over 50% of the cardiovascular deaths among CVD patients comprised older individuals over 75 years of age [6]. Zhao et al. revealed a strong correlation between the TyG index and all-cause/CVD mortality in Americans with diabetes older than 65 years [31]. However, in our study, 82.7% of the participants were younger than 65 years, which might partially explain why the TyG index was not significantly correlated with cardiovascular mortality. Third, this also might be related to the relatively lower value of TyG index in present study. Zhou et al. found that only with a TyG index more than 9.52 will the risk for cardiovascular mortality increase [36]. However, in our study, the third tiles cut-off value of the TyG index was 9.36, which was relatively lower than those of previous studies [6, 37]. Fourth, the TyG index is susceptible to many confounding factors, including the existence of different ailments, the concomitant nutritional status, and altered blood lipid profiles. In our study, the coexisting MetS might have affected the relationship between the TyG index and cardiovascular mortality. Finally, heterogeneity in the study population and the insufficient follow-up time might have affected the relationship between the TyG index and cardiovascular mortality. Overall, more prospective studies are needed to verify the relationship between the TyG index and mortality.

Regarding participants with MetS at baseline, our study suggested that the TyG index can be a useful predictor of all-cause mortality. In rural areas, measuring triglyceride and glucose levels is affordable and easily accessible, with no apparent increase in participant and overall healthcare expenses with the TyG index determination. Previous studies support the TyG index as a reliable indicator for measuring IR and predicting mortality in populations with MetS. Furthermore, this approach may be practical and pragmatic for the large-scale screening of metabolic disorders, particularly in developing countries [7]. The merits of our investigation encompassed a substantial sample size and a longitudinal retrospective approach. This study is the first known attempt to determine the correlation between the TyG index and mortality in a rural Chinese population with MetS. However, the present study had some limitations. First, the participants were from one province in Northeast China, limiting the generalizability of the findings. Second, the TyG index is based on a single blood test, which could introduce potential bias. Third, even after controlling for potential confounding variables, residual confounding factors might have endured. Finally, the influence of prescribed medications on triglyceride and glucose levels could have affected the findings.

Conclusion

The TyG index is a prominent risk predictor of all-cause mortality in participants with MetS in rural China. Our findings indicated that this simple and inexpensive index facilitates the early prediction of mortality in individuals with MetS, aiding village doctors in stratifying high-risk participants and implementing timely interventions.

Abbreviations

BMI	body mass index
CV	cardiovascular
CVD	cardiovascular disease
FPG	fasting plasma glucose
HDL-C	high-density lipoprotein cholesterol
HIEG	hyperinsulinemic euglycemic
HOMA-IR	homeostatic model assessment for insulin resistance
IR	insulin resistance
LDL-C	low-density lipoprotein cholesterol
MetS	metabolic syndrome
TyG	triglyceride-glucose

Acknowledgements

No.

Author contributions

SSY and QYL drafted the manuscript. YXS obtained funding and designed the study. GXL were involved in data cleaning and analyzing. XFG and

HMY collected the data. YXS and XFG contributed to the critical revision of the manuscript. All authors approved the final version of the manuscript. All authors have read and approved the final manuscript. Administrative, technical and logistic support was provided by all authors.

Funding
This study was supported by grants from the National Key Research and Development Program from the Ministry of Science and Technology of China (Project Grant # 2018 YFC 1312400, Sub-project Grant # 2018 YFC 1312403). This study was supported by grants from the 'Support the high-quality development of science and technology fund projects of China Medical University' project funds (grant no. 2023JH2/20200024).

Data availability
Data is available upon the reasonable request of the corresponding author.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics Committee of China Medical University (Shenyang, China AF-SDP-07-1, 0–01). Informed consent was obtained from all subjects involved in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Cardiology, First Hospital of China Medical University, 155 Nanjing North Street, Heping District, Shenyang 110001, China
[2]Department of Clinical Epidemiology, Institute of Cardiovascular Diseases, First Hospital of China Medical University, Shenyang 110001, China

Received: 16 March 2024 / Accepted: 9 May 2024
Published online: 21 May 2024

References

1. Fahed G, Aoun L, Bou Zerdan M, Allam S, Bou Zerdan M, Bouferraa Y, Assi HI. Metabolic syndrome: updates on pathophysiology and management in 2021. Int J Mol Sci. 2022;23(2).
2. Jiang B, Zheng Y, Chen Y, Chen Y, Li Q, Zhu C, Wang N, Han B, Zhai H, Lin D, et al. Age and gender-specific distribution of metabolic syndrome components in East China: role of hypertriglyceridemia in the SPECT-China study. Lipids Health Dis. 2018;17(1):92.
3. Yu S, Guo X, Yang H, Zheng L, Sun Y. An update on the prevalence of metabolic syndrome and its associated factors in rural northeast China. BMC Public Health. 2014;14:877.
4. Chen J, Wu K, Lin Y, Huang M, Xie S. Association of triglyceride glucose index with all-cause and cardiovascular mortality in the general population. Cardiovasc Diabetol. 2023;22(1):320.
5. Liao Y, Zhang R, Shi S, Zhao Y, He Y, Liao L, Lin X, Guo Q, Wang Y, Chen L, et al. Triglyceride-glucose index linked to all-cause mortality in critically ill patients: a cohort of 3026 patients. Cardiovasc Diabetol. 2022;21(1):128.
6. Zhang Q, Xiao S, Jiao X, Shen Y. The triglyceride-glucose index is a predictor for cardiovascular and all-cause mortality in CVD patients with diabetes or pre-diabetes: evidence from NHANES 2001–2018. Cardiovasc Diabetol. 2023;22(1):279.
7. Ramdas Nayak VK, Satheesh P, Shenoy MT, Kalra S. Triglyceride glucose (TyG) index: a surrogate biomarker of insulin resistance. J Pak Med Assoc. 2022;72(5):986–8.
8. Tahapary DL, Pratisthita LB, Fitri NA, Marcella C, Wafa S, Kurniawan F, Rizka A, Tarigan TJE, Harbuwono DS, Purnamasari D, et al. Challenges in the diagnosis of insulin resistance: focusing on the role of HOMA-IR and Tryglyceride/glucose index. Diabetes Metab Syndr. 2022;16(8):102581.
9. Simental-Mendía LE, Rodríguez-Morán M, Guerrero-Romero F. The product of fasting glucose and triglycerides as surrogate for identifying insulin resistance in apparently healthy subjects. Metab Syndr Relat Disord. 2008;6(4):299–304.
10. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, Gordon DJ, Krauss RM, Savage PJ, Smith SC, Jr. et al. Diagnosis and management of the metabolic syndrome. An American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. Executive summary. Cardiol Rev. 2005;13(6):322–327.
11. Li R, Li W, Lun Z, Zhang H, Sun Z, Kanu JS, Qiu S, Cheng Y, Liu Y. Prevalence of metabolic syndrome in Mainland China: a meta-analysis of published studies. BMC Public Health. 2016;16:296.
12. Yu S, Guo X, Li G, Yang H, Sun G, Zheng L, Sun Y. Gender discrepancy of incidence and risk factors of metabolic syndrome among rural Chinese from 2012–2013 to 2015–2017. Diabetol Metab Syndr. 2020;12:48.
13. Report on Cardiovascular Health and Diseases in China 2021: An Updated Summary. Biomed Environ Sci. 2022;35(7):573–603.
14. Bornfeldt KE, Tabas I. Insulin resistance, hyperglycemia, and atherosclerosis. Cell Metab. 2011;14(5):575–85.
15. Won KB, Kim YS, Lee BK, Heo R, Han D, Lee JH, Lee SE, Sung JM, Cho I, Park HB, et al. The relationship of insulin resistance estimated by triglyceride glucose index and coronary plaque characteristics. Med (Baltim). 2018;97(21):e10726.
16. Tam CS, Xie W, Johnson WD, Cefalu WT, Redman LM, Ravussin E. Defining insulin resistance from hyperinsulinemic-euglycemic clamps. Diabetes Care. 2012;35(7):1605–10.
17. Sasaki K, Shoji T, Kabata D, Shintani A, Okute Y, Tsuchikura S, Shimomura N, Tsujimoto Y, Nakatani S, Mori K, et al. Oxidative stress and inflammation as predictors of mortality and cardiovascular events in hemodialysis patients: the DREAM cohort. J Atheroscler Thromb. 2021;28(3):249–60.
18. Ballard-Hernandez J, Sall J. Dyslipidemia update. Nurs Clin North Am. 2023;58(3):295–308.
19. Xin F, He S, Zhou Y, Jia X, Zhao Y, Zhao H. The triglyceride glucose index trajectory is associated with hypertension: a retrospective longitudinal cohort study. Cardiovasc Diabetol. 2023;22(1):347.
20. Wang Y, Yang W, Jiang X. Association between triglyceride-glucose index and hypertension: a meta-analysis. Front Cardiovasc Med. 2021;8:644035.
21. Campos Muñiz C, León-García PE, Serrato Diaz A, Hernández-Pérez E. Diabetes mellitus prediction based on the triglyceride and glucose index. Med Clin (Barc). 2023;160(6):231–6.
22. Shi W, Xing L, Jing L, Tian Y, Liu S. Usefulness of triglyceride-glucose index for estimating hyperuricemia risk: insights from a general population. Postgrad Med. 2019;131(5):348–56.
23. Gao JW, Hao QY, Gao M, Zhang K, Li XZ, Wang JF, Vuitton DA, Zhang SL, Liu PM. Triglyceride-glucose index in the development of peripheral artery disease: findings from the atherosclerosis risk in communities (ARIC) study. Cardiovasc Diabetol. 2021;20(1):126.
24. Barzegar N, Tohidi M, Hasheminia M, Azizi F, Hadaegh F. The impact of triglyceride-glucose index on incident cardiovascular events during 16 years of follow-up: Tehran lipid and glucose study. Cardiovasc Diabetol. 2020;19(1):155.
25. Wu S, Xu L, Wu M, Chen S, Wang Y, Tian Y. Association between triglyceride-glucose index and risk of arterial stiffness: a cohort study. Cardiovasc Diabetol. 2021;20(1):146.
26. Wang X, Xu W, Song Q, Zhao Z, Meng X, Xia C, Xie Y, Yang C, Jin P, Wang F. Association between the triglyceride-glucose index and severity of coronary artery disease. Cardiovasc Diabetol. 2022;21(1):168.
27. Liu X, Tan Z, Huang Y, Zhao H, Liu M, Yu P, Ma J, Zhao Y, Zhu W, Wang J. Relationship between the triglyceride-glucose index and risk of cardiovascular diseases and mortality in the general population: a systematic review and meta-analysis. Cardiovasc Diabetol. 2022;21(1):124.
28. Vega GL, Barlow CE, Grundy SM, Leonard D, DeFina LF. Triglyceride-to-high-density-lipoprotein-cholesterol ratio is an index of heart disease mortality and of incidence of type 2 diabetes mellitus in men. J Investig Med. 2014;62(2):345–9.
29. Liu XC, He GD, Lo K, Huang YQ, Feng YQ. The triglyceride-glucose index, an insulin resistance marker, was non-linear associated with all-cause and cardiovascular mortality in the general population. Front Cardiovasc Med. 2020;7:628109.
30. Shen J, Feng B, Fan L, Jiao Y, Li Y, Liu H, Hou X, Su Y, Li D, Fu Z. Triglyceride glucose index predicts all-cause mortality in oldest-old patients with acute coronary syndrome and diabetes mellitus. BMC Geriatr. 2023;23(1):78.

31. Zhao M, Xiao M, Tan Q, Lu F. Triglyceride glucose index as a predictor of mortality in middle-aged and elderly patients with type 2 diabetes in the US. Sci Rep. 2023;13(1):16478.
32. Li H, Jiang Y, Su X, Meng Z. The triglyceride glucose index was U-shape associated with all-cause mortality in population with cardiovascular diseases. Diabetol Metab Syndr. 2023;15(1):181.
33. Zhou Y, Wang C, Che H, Cheng L, Zhu D, Rao C, Zhong Q, Li Z, Wang X, Wu Z, et al. Association between the triglyceride-glucose index and the risk of mortality among patients with chronic heart failure: results from a retrospective cohort study in China. Cardiovasc Diabetol. 2023;22(1):171.
34. Sánchez-Íñigo L, Navarro-González D, Fernández-Montero A, Pastrana-Delgado J, Martínez JA. The TyG index may predict the development of cardiovascular events. Eur J Clin Invest. 2016;46(2):189–97.
35. Cho YR, Ann SH, Won KB, Park GM, Kim YG, Yang DH, Kang JW, Lim TH, Kim HK, Choe J, et al. Association between insulin resistance, hyperglycemia, and coronary artery disease according to the presence of diabetes. Sci Rep. 2019;9(1):6129.
36. Zhou D, Liu XC, Kenneth L, Huang YQ, Feng YQ. A Non-linear association of triglyceride glycemic index with cardiovascular and all-cause mortality among patients with hypertension. Front Cardiovasc Med. 2022;8:778038.
37. Zhang Y, Ding X, Hua B, Liu Q, Gao H, Chen H, Zhao XQ, Li W, Li H. Predictive effect of triglyceride–glucose index on clinical events in patients with type 2 diabetes mellitus and acute myocardial infarction: results from an observational cohort study in China. Cardiovasc Diabetol. 2021;20(1):43.

Publisher's Note