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Triglyceride–glucose index associates with incident heart failure: A cohort study

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ABSTRACT

Aims: Triglyceride–glucose (TyG) index has been proposed as a simple surrogate marker of insulin resistance. However, few studies have investigated the association of TyG index with heart failure (HF). We aimed to explore the relationship between TyG index and incident HF.
Methods: A total of 138,620 participants from the Kailuan study were included for analysis. TyG index was calculated as ln [fasting triglyceride (mg/dL) × fasting glucose (mg/dL) / 2]. Cox proportional hazard models were used to investigate the association between TyG index and the risk of HF. Restricted cubic spline analysis was applied to evaluate the dose-response relationship between TyG index and the risk of HF.
Results: There were 1602 incident HF cases among the 138,620 participants during a median follow-up of 8.78 years. Compared with those in the lowest quartile group of TyG index, participants with the highest quartile of TyG index had a 24% higher risk of HF (HR=1.24, 95%CI=1.07-1.44) after adjusting for other risk factors. Restricted cubic spline analysis showed a significant J-shaped dose-response relationship between TyG index and risk of HF (P for non-linearity < 0.001). The significant association was still observed among the men and participants with or without abdominal obesity in subgroup analyses.
Conclusion: The TyG index was positively associated with the risk of HF, which indicates that the TyG index might be useful to identify people at high-risk for developing HF.

Introduction

Heart failure (HF) is a complex clinical condition that is characterized by impaired cardiac structure and function as well as altered neurohormonal regulation [1]. This condition has become a major reason for morbidity and mortality, with an estimated prevalence of more than 64.3 million people worldwide [2,3]. The American Heart Association estimates that the prevalence of HF will continue to increase, carrying with it an increasing economic and social burden [4]. Hence, novel preventive approaches focusing on key risk factors for HF are urgently needed to combat this growing trend.

Generally, unfavorable levels of blood glucose and cholesterol have been recognized as major modifiable metabolic risk factors for HF. From this perspective, the triglyceride–glucose (TyG) index, a new indicator derived from fasting blood glucose (FBG) and fasting triglyceride (TG) levels [5], might have potential as a marker for HF. An increasing number of studies have reported a positive correlation between the TyG index and cardiovascular diseases such as stroke, myocardial infarction, and arterial stiffness [6–8]. However, there is limited information regarding the association between the TyG index and the risk of HF. To fill this knowledge gap, the current study based on the Kailuan cohort was conducted to investigate the association between the TyG index and incident of HF.

Methods

Study population

The study participants were extracted from a prospective cohort within the Kailuan community in Tangshan city, China, as described previously [9]. A total of 159,108 participants completed the first survey, including questionnaires, physical examinations, and laboratory assessments, in 2006–2007, 2008–2009, 2010–2011, or 2012–2013

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at Kailuan General Hospital and 10 affiliated hospitals, with a biennial follow-up. Participants who satisfied the following criteria at the first survey were included: (1) complete data for FBG and TG; (2) absence of cancer or cardiovascular diseases; (3) no FBG- or TG-lowering medications; and (4) age 20–80 years. Finally, 138,620 participants were included in the analysis.

The study was performed in accordance with the guidelines of the Declaration of Helsinki and was approved by the Ethics Committee of the Kailuan General Hospital (Approval Number: 2006-05). All participants agreed to participate in the study and provided written informed consent.

Data collection and definition

Information regarding the patients' demographics (e.g., age, sex, and education), medical history (e.g., medications), and lifestyle (e.g., smoking status, alcohol consumption, physical activity, and salt intake) was collected using a structural questionnaire. Smoking and drinking status were stratified into two levels according to the current status (yes/no). Active physical activity was defined as exercise for more than four times per week with each session lasting at least 20 min [10,11]. Anthropometric data were measured by trained staff, including weight, height, and waist circumference (WC). Body mass index (BMI) was calculated as the weight (kg)/height $(m)^2$. Abdominal obesity was defined as WC ≥102 cm in men or WC ≥ 88 cm in women [12]. Blood pressure was measured twice at intervals of 5 min on the left upper arm by a certified nurse using a calibrated mercury sphygmomanometer after the participants rested in the sitting position for 5 min. When the difference between two measurements was >5 mmHg, the blood pressure was measured again. The final blood pressure was the average of two or three measurements. Hypertension was defined as systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg, use of antihypertensive medications, or a self-reported history of hypertension.

Biochemical measurements

Blood samples from each participant were collected in EDTA tubes after fasting for 8–10 h and centrifuged at 3000*g* for 10 min to separate plasma. FBG was measured using the hexokinase/glucose-6-phosphate dehydrogenase method, and the coefficient of variation using blind quality control specimens was <2.0% [13]. TG, total cholesterol (TC), high-density lipoprotein (HDL), and low-density lipoprotein (LDL) were examined using enzymatic assays (inter-assay coefficient of variation <10%). Plasma high-sensitivity C-reactive protein (hs-CRP) levels were measured using a high-sensitivity particle-enhanced immunonephelometric assay. Creatinine levels were measured using a sarcosine oxidase assay (Creatinine kit, BioSino Bio-Technology and Science Inc, Beijing, China) [14]. Estimated glomerular filtration rate (eGFR) was calculated using a modified four-variable Chronic Kidney Disease Epidemiology Collaboration formula with an adjusted coefficient of 1.1 for the Chinese population [15]. An automatic biochemical analyzer (Hitachi 747; Hitachi, Tokyo, Japan) was employed to measure all biochemical variables at the central laboratory of Kailuan General Hospital. TyG index was calculated as ln [fasting triglyceride (mg/dL) × fasting glucose (mg/dL) / 2] [5].

HF and follow-up

The primary endpoint was newly diagnosed HF events. Participants were followed from baseline to the date of HF events or until December 31, 2015, whichever was earlier. In the present study, potential cases of incident HF were ascertained from the discharge summaries of the 11 hospitals, death certificates, or medical insurance records and were updated annually during the follow-up period [16]. A panel of three cardiologists reviewed the medical records of patients with potential HF identified using ICD codes (I50). HF was clinically diagnosed on the basis of clinical symptoms, echocardiography, chest radiography, and electrocardiography according to the criteria of the European Society of Cardiology [17].

Statistical analysis

Multiple imputations of missing values were performed. The proportions of missing data for sex, education, physical activity, smoking, alcohol drinking, salt intake, BMI, WC, SBP, DBP, TC, HDL, LDL, hs-CRP and eGFR were 0.57%, 3.55%, 3.37%, 3.23%, 3.24%, 3.37%, 0.76%, 4.26%, 0.88%, 0.88%, 0.02%, 0.01%, 0.03%, 5.67% and 3.01%, respectively, while other variables (age, FBG, TG, and hypertension) were complete. We conducted 20 rounds of multiple imputations, then combined them into final estimates according to Rubin's rule (function "with/pool" in R package "mice") [18,19]. Continuous variables were expressed as mean ± standard deviation (SD) or medians with interquartile ranges depending on their distributions, and categorical variables were expressed as frequencies and percentages. To compare the characteristics among different TyG index groups, the chi-square test was performed for categorical variables and one-way analysis of variance or the Kruskal–Wallis test was performed for continuous variables with normal and skewed distributions. Bonferroni correction was performed for further multiple comparisons.

Multivariable Cox proportional hazard regression analyses were performed to estimate the independent association between the TyG index and the risk of HF, with adjustment for age, sex, education, physical activity, smoking, alcohol drinking, salt intake, WC, LDL level, hs-CRP level, hypertension, and eGFR. The Schoenfeld residuals were used to assess the proportional hazards assumption, with the results indicating no significant departure from proportionality in hazards over time. We also explored the nonlinear dose–response relationship between the TyG index and the risk of HF using a restricted cubic spline model with three knots (at the 10^{th}, 50^{th}, and 90^{th} percentiles). Subgroup analyses according to age (<50 years and ≥50 years), sex and WC (men ≥ 102 cm or women ≥ 88 cm and men < 102 cm or women < 88 cm) were performed to explore potential modification effects. The interaction effect was estimated using the Wald test. To account for the possibility of reverse causation, a Cox proportional hazards model was constructed after excluding participants with less than 2 years of follow-up for sensitivity analysis. All statistical analyses were performed using R software (version 4.0.2), with a two-tailed *P* value of <0.05 indicating statistical significance.

Results

Baseline characteristics of the participants

A total of 138,620 (male, 79.5%) eligible participants were included in this study. The baseline characteristics and laboratory parameters grouped according to the quartiles of baseline TyG index are presented in Table 1. Compared with individuals in the lowest quartile group according to the TyG index, those in the highest quartile were more likely to be men, older, less educated, abdominally obese, and current smokers and drinkers and have higher blood pressure and hs-CRP levels and lower eGFR. Most variables shown in Table 1 differed between the quartile groups even after a Bonferroni correction for multiple comparisons.

Association between the TyG index and HF

The association between the TyG index and the risk of HF is presented in Table 2. Over a median follow-up period of 8.78 years, 1602 cases of incident HF occurred among the 138,620 participants. The incidence rates of HF according to the TyG index quartiles were 1.19, 1.34, 1.58, and 1.99 per 1000 person-years, respectively. After

Table 1
Baseline characteristics of participants based on quartiles of TyG index (n=138620)

Characteristics	Quartiles of TyG index				*P* value
	Q1 (6.77-8.16)	Q2 (8.16-8.55)	Q3 (8.55-9.00)	Q4 (9.00-11.65)	
Age, years	46 ± 14	48 ± 14	50 ± 13	50 ± 12	*P*<0.001
Male	25072 (72)	27512 (79)	28533 (82)	29808 (86)	*P*<0.001
Education					*P*<0.001
<high school	2759 (8)	2751 (8)	2931 (9)	2915 (8)	
high school	20925 (60)	22939 (66)	23002 (66)	23624 (68)	
>high school	10970 (32)	8958 (26)	8728 (25)	8117 (23)	
Active physical activity	4943 (14)	4764 (14)	5108 (15)	4722 (14)	*P*<0.001
Current smoker	11232 (32)	11492 (33)	12447 (36)	13908 (40)	*P*<0.001
Current alcohol drinking	12169 (35)	12161 (35)	13270 (38)	14813 (43)	*P*<0.001
Salt intake					*P*<0.001
<6g/day	3812 (11)	3632 (11)	3636 (11)	3439 (10)	
6-10g/day	27349 (79)	27626 (80)	27246 (79)	27196 (79)	
>10g/day	3493 (10)	3390 (10)	3779 (11)	4021 (12)	
BMI, kg/m^2	23.2 ± 3.2	24.4 ± 3.3	25.5 ± 3.3	26.4 ± 3.4	*P*<0.001
Waist circumferences, cm	82 (75-88)	85 (79-90)	87 (82-94)	90 (85-96)	*P*<0.001
FBG, mmol/L	4.8 (4.4-5.2)	5.0 (4.7-5.5)	5.2 (4.8-5.8)	5.6 (5.0-6.4)	*P*<0.001
SBP, mmHg	120 (110-131)	122 (112-140)	130 (119-140)	130 (120-147)	*P*<0.001
DBP, mmHg	80 (70-84)	80 (75-90)	81 (79-90)	85 (80-92)	*P*<0.001
TC, mmol/L	4.5 (4.0-5.1)	4.8 (4.2-5.4)	5.0 (4.4-5.6)	5.2 (4.5-5.9)	*P*<0.001
TG, mmol/L	0.7 (0.6-0.8)	1.1 (0.9-1.2)	1.5 (1.3-1.7)	2.6 (2.1-3.7)	*P*<0.001
HDL, mmol/L	1.5 (1.3-1.8)	1.5 (1.3-1.7)	1.4 (1.2-1.7)	1.4 (1.2-1.7)	*P*<0.001
LDL, mmol/L	2.2 (1.7-2.8)	2.4 (2.0-2.9)	2.5 (2.0-3.0)	2.4 (1.9-3.0)	*P*<0.001
TyG index	7.8 ± 0.2	8.4 ± 0.1	8.8 ± 0.1	9.5 ± 0.4	*P*<0.001
hs-CRP, mg/L	0.7 (0.3-1.9)	0.8 (0.3-2.0)	1.0 (0.4-2.3)	1.1 (0.5-2.7)	*P*<0.001
eGFR	89.7 ± 20.5	85.6 ± 21.7	84.7 ± 21.3	83.7 ± 22.4	*P*<0.001
Hypertension	8612 (25)	12326 (36)	15016 (43)	17981 (52)	*P*<0.001

Note: Data are presented as mean ±SD or median (interquartile range) or n (%). BMI, body mass index; FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; TG, triglyceride; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TyG index, triglyceride–glucose index; hs-CRP, high-sensitivity C-reactive protein; eGFR, estimated glomerular filtration rate

adjusting for age, sex, education, physical activity, smoking status, alcohol drinking, and salt intake, the hazard ratios (HRs) and 95% confidence intervals (95% CIs) for incident HF in model 1 were 1.04 (0.89−1.22), 1.20 (1.04−1.40), and 1.60 (1.39−1.84) in the second, third, and fourth quartiles, respectively, with the first quartile serving as a reference. However, after additionally adjusting for WC, LDL level, hs-CRP level, hypertension, and eGFR, a significant association was only observed in the highest quartile group (OR=1.24, 95%CI=1.07-1.44). Moreover, restricted cubic spline analysis (Fig. 1) indicated a significant J-shaped dose−response relationship between the TyG index and risk of HF (*P* for non-linearity < 0.001).

Subgroup analysis for the association of TyG index with HF

Subgroup analyses were performed to stratify the association between TyG index and HF by age, sex, and WC, as provided in Fig. 2. The significant association between the TyG index and risk of HF persisted among male and participants with or without abdominal obesity. No interaction was found between subgroup variables and association of TyG index with the risk of HF.

Sensitivity analysis

Sensitivity analysis was performed after excluding participants with <2 years of follow-up (Table 3). Notably, 1357 cases of incident HF occurred among the remaining 136,640 participants. The association persisted in the multivariable model after adjusting for potential confounding factors, and the adjusted HRs (95% CIs) for incident HF were 0.91 (0.77−1.08), 1.03 (0.88−1.22), and 1.24 (1.06−1.45) in the second, third, and fourth TyG index quartiles, respectively, with the lowest quartile serving as reference.

Discussion

This study investigated the relationship between the TyG index and incident HF in Chinese adults. The findings showed that the risk

Table 2
HR (95% CI) for risk of HF according to quartiles of TyG index

Variables	Quartiles of TyG index			
	Q1 (6.77-8.16)	Q2 (8.16-8.55)	Q3 (8.55-9.00)	Q4 (9.00-11.65)
Case, n	305	351	417	529
Incidence, per 1000 person-years	1.19	1.34	1.58	1.99
Model 0	Reference	1.12 (0.96-1.30)	1.31 (1.13-1.52) **	1.65 (1.44-1.90) **
Model 1	Reference	1.04 (0.89-1.22)	1.20 (1.04-1.40) *	1.60 (1.39-1.84) **
Model 2	Reference	0.95 (0.81-1.10)	1.01 (0.87-1.18)	1.24 (1.07-1.44) *

Note: CI, confidence interval; HR, hazard ratio; HF, heart failure; TyG index, triglyceride−glucose index;
* *P*<0.05
** *P*<0.001;
Model 0: unadjusted
Model 1: adjusted for age, sex, education, physical activity, smoking, alcohol drinking, and salt intake
Model 2: adjusted for WC, LDL, hs-CRP, hypertension, and eGFR on the basis of the model 1

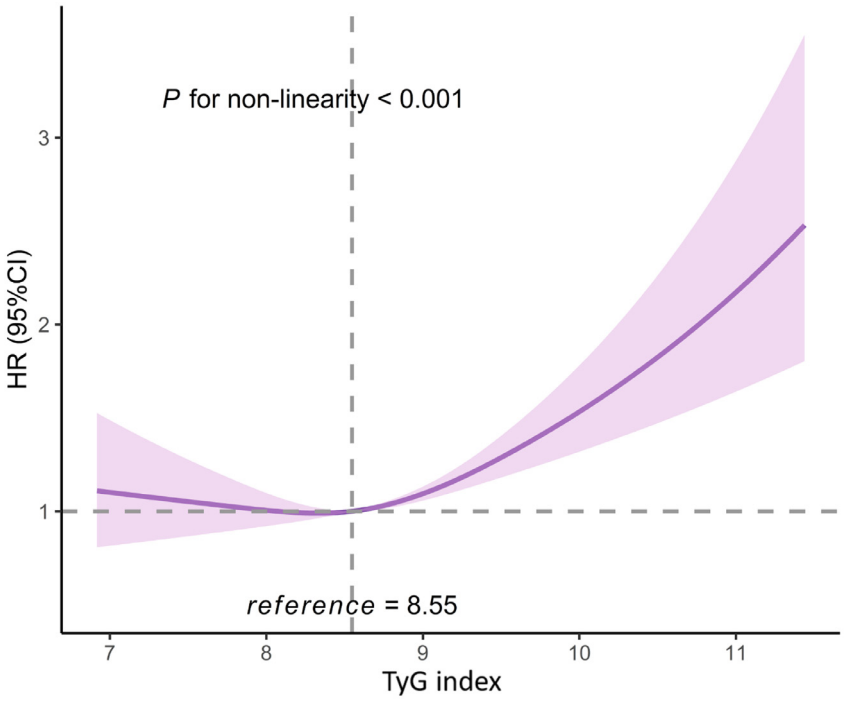

Fig. 1. Dose-response relationship between TyG index and risk of heart failure.

Note: Abbreviation: TyG index, triglyceride-glucose index; HR, hazard ratio; CI, confidence interval. Restricted cubic spline curve was carried out with 3 knots at 10th, 50th, and 90th percentiles of baseline TyG index. The reference point was the median of the TyG index in the 138620 participants. The solid line represented point estimation on the association of TyG index with heart failure, and the shaded portion represented 95% CI estimation. Covariates in the model included age, sex, education, physical activity, smoking, alcohol drinking, salt intake, WC, LDL, hs-CRP, hypertension and eGFR.

Subgroup	Case,n	Incidence	Model 0	Model 1	Model 2
Age < 50 years			HR (95%CI)	HR (95%CI)	HR (95%CI)
Q1 (6.77-8.16)	37	0.27	Reference	Reference	Reference
Q2 (8.16-8.55)	51	0.41	1.49 (0.97-2.28)	1.33 (0.87-2.05)	1.11 (0.72-1.71)
Q3 (8.55-9.00)	43	0.36	1.31 (0.84-2.04)	1.13 (0.73-1.77)	0.83 (0.53-1.31)
Q4 (9.00-11.65)	83	0.67	2.46 (1.67-3.63)	2.02 (1.35-3.00)	1.26 (0.83-1.90)
Age≥50 years					
Q1 (6.77-8.16)	268	2.28	Reference	Reference	Reference
Q2 (8.16-8.55)	300	2.21	0.97 (0.82-1.14)	0.98 (0.83-1.15)	0.87 (0.74-1.03)
Q3 (8.55-9.00)	374	2.59	1.14 (0.97-1.33)	1.16 (0.99-1.36)	0.96 (0.82-1.13)
Q4 (9.00-11.65)	446	3.12	1.37 (1.18-1.59)	1.40 (1.21-1.64)	1.06 (0.90-1.24)
Male					
Q1 (6.77-8.16)	271	1.46	Reference	Reference	Reference
Q2 (8.16-8.55)	308	1.49	1.01 (0.86-1.19)	1.04 (0.88-1.22)	0.94 (0.80-1.11)
Q3 (8.55-9.00)	372	1.72	1.17 (1.00-1.37)	1.23 (1.05-1.44)	1.04 (0.89-1.22)
Q4 (9.00-11.65)	449	1.97	1.34 (1.15-1.56)	1.55 (1.33-1.80)	1.22 (1.04-1.43)
Female					
Q1 (6.77-8.16)	34	0.48	Reference	Reference	Reference
Q2 (8.16-8.55)	43	0.79	1.61 (1.02-2.53)	1.03 (0.65-1.62)	0.93 (0.59-1.47)
Q3 (8.55-9.00)	45	0.94	1.91 (1.22-2.99)	0.94 (0.59-1.48)	0.80 (0.51-1.28)
Q4 (9.00-11.65)	80	2.08	4.21 (2.81-6.30)	1.71 (1.13-2.58)	1.31 (0.85-2.02)
Non-abdominal obesity					
Q1 (6.77-8.16)	281	1.18	Reference	Reference	Reference
Q2 (8.16-8.55)	289	1.22	1.02 (0.87-1.21)	0.96 (0.81-1.13)	0.91 (0.77-1.07)
Q3 (8.55-9.00)	338	1.46	1.22 (1.04-1.43)	1.15 (0.98-1.34)	1.05 (0.90-1.24)
Q4 (9.00-11.65)	390	1.75	1.46 (1.25-1.70)	1.45 (1.24-1.69)	1.29 (1.10-1.51)
Abdominal obesity					
Q1 (6.77-8.16)	24	1.30	Reference	Reference	Reference
Q2 (8.16-8.55)	62	2.52	1.93 (1.20-3.10)	1.73 (1.07-2.77)	1.63 (1.01-2.62)
Q3 (8.55-9.00)	79	2.41	1.85 (1.17-2.93)	1.52 (0.96-2.41)	1.39 (0.88-2.21)
Q4 (9.00-11.65)	139	3.22	2.47 (1.60-3.82)	2.13 (1.38-3.30)	1.88 (1.21-2.92)

Fig. 2. Subgroup analyses of the association between the TyG index and risk of heart failure.

Note: Abbreviation: TyG index, triglyceride-glucose index; HR, hazard ratio; CI, confidence interval. Q, quartile.

Incidence, per 1000 person years.

Non-abdominal obesity: Waist circumference < 102 cm in men or waist circumference < 88 cm in women; Abdominal obesity: Waist circumference ≥ 102 cm in men or waist circumference ≥ 88 cm in women.

Model 0: unadjusted; Model 1: adjusted for age, sex, education, physical activity, smoking, alcohol drinking, and salt intake; Model 2: adjusted for WC, LDL, hs-CRP, hypertension, and eGFR on the basis of the model 1.

Table 3
HR (95% CI) for risk of HF by quartiles of TyG index in sensitivity analysis (N=136640)

Variables	Quartiles of TyG index			
	Q1 (6.77-8.16)	Q2 (8.16-8.55)	Q3 (8.55-9.00)	Q4 (9.00-11.65)
Case, n	260	287	361	449
Incidence, per 1000 person-y	1.02	1.10	1.38	1.70
Model 0	Reference	1.07 (0.90-1.26)	1.32 (1.13-1.55) **	1.63 (1.40-1.90) **
Model 1	Reference	1.00 (0.85-1.18)	1.22 (1.04-1.44) *	1.59 (1.36-1.85) **
Model 2	Reference	0.91 (0.77-1.08)	1.03 (0.88-1.22)	1.24 (1.06-1.45) *

Note: Table 3 showed HR (95% CI) for risk of HF by quartiles of TyG index in sensitivity analysis with participants followed for more than two years (N=136640);
* $P<0.05$
** $P<0.001$
CI, confidence interval; HR, hazard ratio; HF, heart failure; TyG index, triglyceride−glucose index;
Model 0: unadjusted
Model 1: adjusted for age, sex, education, physical activity, smoking, alcohol drinking, and salt intake
Model 2: adjusted for WC, LDL, hs-CRP, hypertension, and eGFR on the basis of the model 1

of HF was significantly associated with baseline TyG index values after adjusting for age, sex, education, physical activity, smoking status, alcohol consumption, salt intake, WC, LDL level, hs-CRP level, hypertension, and eGFR. Additionally, a significant J-shaped dose−response relationship was observed between the TyG index and risk of incident HF, which indicated that the risk of HF increased rapidly when the TyG index exceeded the median value (i.e., 8.55). To the best of our knowledge, this is the first study to show a relationship between the TyG index and incident HF in a large and prospective cohort.

Similar to the present study, previous publications have indicated that the TyG index was positively associated with rehospitalization and prognosis of HF [20,21]. However, a cross-sectional study by UK Biobank reported no significant association between the TyG index and HF [22]. The present study, based on a 9-year follow-up cohort, revealed a positive association between the TyG index and initial-onset HF, which could be attributed to insulin resistance (IR). Several studies have reported that the TyG index closely mirrors the glucose clamp technique and homeostasis model assessment−insulin resistance (HOMA-IR) index in the assessment of insulin sensitivity [23−25]. Therefore, the TyG index has been proposed as a surrogate of IR. Previous findings have suggested that IR was associated with increased risk of developing HF [26,27]. For instance, Ingelsson et al. found that IR measured using pro-insulin levels and euglycemic insulin clamp testing was independently associated with the risk of HF based on the Uppsala Longitudinal Study of Adult Men. Similarly, the Cardiovascular Health Study and Atherosclerosis Risk in Communities Study showed a positive association between IR, assessed using fasting insulin and HOMA-IR, and an increased risk of subsequent HF [28,29]. Our findings observed that the TyG index was significantly associated with incident HF, which corroborated the aforementioned investigations, and established an association between IR and risk of HF, despite difference in the assessment of IR.

Some biological mechanisms may explain the association between IR and HF. First, because of impaired glucose utilization, IR facilitates a shift in myocardial substrate toward increased free fatty acid oxidation, causing a decrease in metabolic efficiency [30]. This metabolic disorder increases susceptibility to pressure overload or ischemia, promoting the initiation or exacerbation of HF [31,32]. Moreover, hyperinsulinemia, which is associated with sympathetic nervous system activation and a more pronounced angiotensin II response [33], may contribute to cardiac remodeling via inflammation, cardiac fibrosis, and oxidative stress [34−36]. Additionally, the present study observed a slight decrease in HR for the positive association between the TyG index and risk of HF, after adjusting for additional health factors, including WC, LDL, and hypertension based on model 1, and the association only remained significant in the highest quartile group. This finding was consistent with that presented in previous studies, which showed that IR could increase the risk of HF partly through indirect effects, including abdominal obesity, hypertension, and dyslipidemia [37].

HF is a common condition that accounts for a significant portion of health care expenditures. Thus, there is a need to identify modifiable risk factors for HF from a public health perspective so as to establish early lifestyle changes to prevent HF. As an important risk factor of HF, IR has largely been considered to predict the development of HF. The gold standard test for IR was the hyperinsulinemic-euglycemic clamp, which was laborious and costly and replaced by HOMA-IR in the previous studies. However, as insulin is not usually available in clinical practice, it is not possible to determine HOMA-IR, and the TyG index is more suitable for large-scale application in clinical practice due to its high sensitivity and low cost [5]. Emerging studies have suggested that the TyG index could predict the development of cardiovascular diseases such as stroke, myocardial infarction, coronary heart disease, and cerebrovascular disease [38−40]. Our findings fill the gap in information regarding the association between the TyG index and incident HF by showing a J-shaped dose−response relationship. In those with TyG index less than 8.55, we observed a slight increase in risk of HF as TyG index decreased, which may be related to undernutrition and very low triglycerides. However, these results seem to not reach statistical significance in the present study, and most participants have good nutrition status based on their BMI status. Therefore, the association between low TyG index levels and HF remains to be further explored. In addition, among the participants with a TyG index over 8.55, the risk of HF increased rapidly with increasing TyG index values. This suggests that maintaining a TyG index below 8.55 may be helpful in reducing the risk of developing HF. Given the rather limited research on this issue to date, more studies are needed to determine the optimal reference range of the TyG index for preventing HF in clinical practice.

There are several strengths in our study. First, previous studies have only explored the association between TyG index and prognosis of HF, but not incident HF. We filled the gap and indicated the predictive value of TyG index for the development of HF, which was clinically meaningful. Second, this study was based on Kailuan cohort, which is characterized by a prospective design, large community-based sample, and long follow-up period. However, the current study also has several limitations. First, although our model had adjusted for most demographic and clinical variables, some residual or unmeasured confounding parameters were unavailable owing to the study design. Second, considering that all participants included were from the Kailuan community, more research on other populations is needed to increase the generalizability of our findings. Third, given the lack of records on serum insulin, we were unable to compare the TyG index with HOMA-IR and the hyperinsulinemic-euglycemic clamp test.

Conclusions

The TyG index was positively associated with the risk of HF in a J-shaped dose–response relationship. These findings indicate that the TyG index might serve as an easy and reliable marker for the early identification of individuals at high-risk for developing HF.

Authors' contributions

Luli Xu, and Mingyang Wu made substantial contributions to the conception and design of the study, data collection and analysis, drafting of the manuscript and served as the equally contributing first authors of the manuscript. Youjie Wang, Shouling Wu and Yaohua Tian made substantial contributions to study design, intellectual direction, and revision of the drafting of the manuscript. Shuohua Chen made contributions to data collection, and Yingping Yang made contributions to data analysis. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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