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Associations between triglyceride-glucose index combined with waist circumference and heart failure in individuals with different body mass indices: a cross-sectional study using NHANES 2011–2020 data

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Abstract

Introduction The incidence of heart failure (HF), a cardiovascular disease, has been widely reported to be gradually increasing. Although the triglyceride-glucose (TyG) index is associated with the risk of HF, this relationship may be affected by differences in nutritional status among individuals with varying levels of obesity. Waist circumference combined with the TyG index may be more accurately associated with HF.

Methods This study analyzed data from 8769 participants from the 2011–2020 National Health and Nutrition Examination Survey (NHANES). After weighting the data, multivariable logistic regressions were used to calculate the associations between HF and the TyG and TyG-waist circumference (TyG-WC) indices in adults with different body mass indices (BMIs). Restricted cubic splines were employed to assess for linear or nonlinear relationships. Receiver operating characteristic (ROC) curves were used to demonstrate the efficacy of the models for different indices. The Net Reclassification Index (NRI) was used to measure the improvement in the TyG-WC index relative to the TyG index in the different models. The Integrated Discriminant Improvement Index (IDI) supports this conclusion.

Results TyG and TyG-WC indices were positively associated with HF (TyG: odds ratio [OR], 1.765; 95% CI], 1.390–2.242; $P < 0.001$; TyG-WC: OR, 1.003; 95% CI, 1.002–1.004; $P < 0.001$), except In Model 4 for the TyG index (OR, 1.238; 95% CI, 0.941–1.629; $P = 0.124$). BMI was used to categorize the study population into normal or underweight and overweight or obese groups. In the overweight and obese groups, the odds ratio (OR) increased as the index value increased. However, in the normal and underweight groups, high TyG indices were associated with low ORs. According to the

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ROC, NRI, and IDI analyses, the TyG-WC index was associated with HF in the normal weight or underweight groups (area under the curve [AUC]: 0.6724; 95% CI: 0.4991-0.6400), whereas the TyG index alone was not (AUC: 0.5695; 95% CI: 0.6115–0.7334). In Model 4, adjusted for all covariates, the TyG index had a slightly better ability than the TyG-WC index (NRI: -0.4112; 95% CI: -0.6818- -0.1406; $P < 0.05$; IDI: -0.0072; 95%CI: -0.0228-0.0083; $P = 0.36256$). In the overweight and obese populations, the TyG-WC index was slightly better than the TyG index (NRI: 0.3089; 95% CI: 0.1726–0.4451; $P < 0.001$; IDI: 0.0084; 95% CI: 0.0017–0.0151; $P < 0.05$). However, the sensitivity of the TyG-WC index alone was only 41.8%.

Discussion The association between HF and these two indices was influenced by BMI. In normal-weight and underweight populations, higher TyG indices may imply improved nutritional status. Therefore, the TyG index should be combined with WC to assess the risk of HF. In overweight or obese populations, both indices can be used to assess the risk of HF; however, the TyG-WC index is less sensitive when used alone.

Keywords Heart failure, The TyG index, BMI, The TyG-WC index

Introduction

Heart failure (HF) is a prevalent disease worldwide. Recently, HF with preserved ejection fraction (HFpEF) has become common [1]. Conversely, the quantity of HF with reduced ejection fraction (HFrEF) has remained stable or declined [2]. HF morbidity has either settled or declined [3]. The prognosis of patients with HF has improved, but the mortality and healthcare burden remain high [4]. Accurate recognition and careful assessment of changes in patient indicators and their association with HF are critical in clinical practice.

Approximately 30–40% of patients with HF whether ejection fraction is decreased or preserved develop type 2 diabetes (T2DM) as a complication [1]. T2DM increases the all-cause mortality in HF [5]. However, T2DM is often overlooked in patients with HF. Therefore, the association between these two diseases is important. T2DM is strongly associated with insulin resistance (IR). In recent years, clinicians have often used the homeostasis model assessment for insulin resistance (HOMA-IR) index to assess IR. However, in patients managed with insulin or with complete loss of pancreatic β-cell function, the value of HOMA-IR assessment is limited [6]. The formula for the TyG index is TyG = ln (triglyceride × fasting plasma glucose/2), which addresses this limitation to a certain extent. Studies have shown that it is an influencing factor for outcomes in patients with cardiovascular diseases (CVD) with or without diabetes mellitus, suggesting that the TyG index has valuable applications for clinicians [7]. Zhang et al. studied data from 615 patients with cardiovascular disease who had diabetes or prediabetes. The study showed that the baseline TyG index had a U-shaped relationship with all-cause and CVD-related deaths. Before and after the threshold, the TyG index was strongly associated with mortality in patients with cardiovascular disease [8]. In addition, Zhu et al. studied a cohort of 2,033 patients with hypertension. They found a nonlinear relationship between the TyG index and the development of chronic kidney disease after 31 months of follow-up. The hazard ratio decreased until TyG was approximately 8.94 and then increased rapidly. This study showed that the TyG index is strongly associated with cardiovascular and kidney diseases [9].

In recent years, interest in fat distribution has gradually increased. In their review, Powell-Wiley et al. highlighted that recent studies suggested that waist circumference, which determines the degree of abdominal obesity, is an indicator of cardiovascular disease risk, independent of body mass index (BMI) [10]. Dang et al. demonstrated that the TyG-WC index (TyG-WC = TyG × WC) improved the prediction of CVD prognosis and mortality. In addition, their data suggested that the TyG-WC might be an effective indicator for recognizing people with CVD earlier and facilitating complete risk stratification [11]. Hu et al. included 2224 Chinese patients with hypertension and no history of myocardial infarction. After 7.15 years of follow-up, they found that TyG-WC was positively associated with the risk of the first myocardial infarction [12].

The TyG and TyG-WC indices can be influenced by many factors when analyzing their associations with cardiovascular disease outcomes. Few studies have selected these as stratification factors for subgroup analyses. In addition, few studies have examined the association between these two indices and HF. In this study, associations between the two indices and HF were analyzed across various models for subgroups classified by the BMI which was chosen from the subgroup analysis. In addition, TyG and TyG-WC were compared using accurate methods such as the NRI and IDI to provide clarification for clinicians in selecting indices for HF observation.

Methods

Screening of study participants

Data from the National Health and Nutrition Examination Survey (NHANES) from 2011 to 2020 were included. The NHANES database can be used to assess the nutritional status of individuals in the United States.

Demographic, clinical, laboratory, and questionnaire data were collected. Demographic characteristics, WC, weight, height, fasting glucose level, triglyceride level, and other indicators that may affect the outcome were selected for analysis.

Different participants had different missing data points. These were related to other variables; therefore, they could not be filled in with the median. Predicting missing data for each participant is extremely tedious. Considering that a large sample size remained after excluding those with missing data, participants with missing data on HF, TyG index, WC, weight, or other covariates were excluded. Furthermore, based on the screening methods for American adults from the NHANES in published articles [13, 14], participants younger than 20 years were excluded. Disease diagnoses were binary variables; therefore, those whose responses to questions regarding disease diagnoses were unclear were excluded. Participants without weighted data were excluded. Ultimately, 8769 participants were enrolled in the study. A flowchart of the screening process is shown in Fig. 1.

Variable selection

Questions from the medical conditions section of the questionnaire data were utilized to diagnose HF. People who answered yes to MCQ160b —Ever told you had congestive heart failure— were identified as having had HF. The TyG index required manual calculation, using the LBXTR-triglyceride and LBXGLU-fasting glucose laboratory data from the NHANES database. TyG was categorized into tertiles Q1-TyG, Q2-TyG, or Q3-TyG. To calculate TyG-WC, the BMXWAIST-waist circumference (cm) data from the body measures section were collected. TyG-WC was also categorized into tertiles Q1-TyG-WC, Q2-TyG-WC, or Q3-TyG-WC.

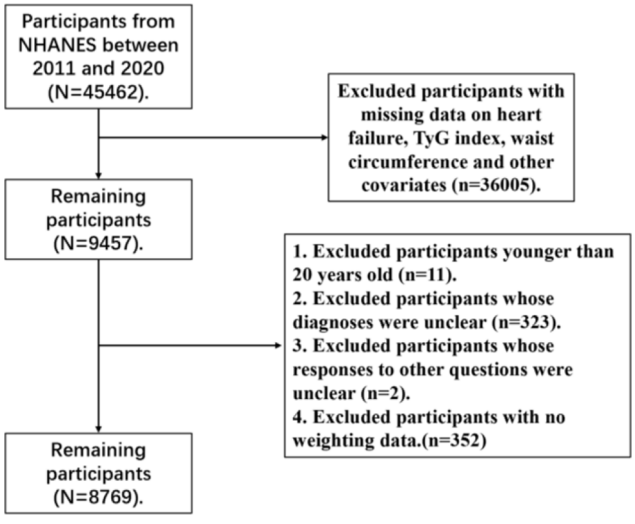

Fig. 1 The flowchart of screening study subjects

In addition, covariates that may have a significant impact on the outcome were integrated, including age, sex, race, education, income, BMI, and some biochemical indices such as indicators of lipid and glucose metabolism, as well as data on complications such as diabetes and cardiovascular diseases.

BMI values referenced the BMXBMI-body mass index (kg/m^2) examination data and the populations were classified using BMI into two groups, the normal or thin and the overweight or obese group, respectively. Educational status was determined by the DMDEDUC2-education level-adults 20 or older demographic data. Income levels were determined using the INDFMPIR-ratio of family income to poverty levels from the demographic data, with the values of 0–4.98 categorized as low and 5 classified as high. Participants who answered yes to DIQ010, MCQ160f, BPQ020, MCQ160d, MCQ160c, or MCQ160e were considered to have diabetes, stroke, hypertension, angina, coronary heart disease, or myocardial infarction, respectively.

Statistical analysis

R Studio (version 4.3.1) was used for analysis. *P*-values less than 0.05 were considered significant. The NHANES obtained samples through complex multistage sampling, and its recommendations were used to calculate the weights of the data. When baseline data were compared according to the classification of whether the participant had HF and two indices, $\chi 2$ or Fisher's exact tests, the Mann–Whitney U or Kruskal–Wallis tests were used. Medians, along with the upper and lower quartiles, were used to represent the distribution of continuous variables. The counts and composition ratios are shown in the tables to represent the distribution of categorical variables.

Multivariable logistic regression analysis helped reveal the associations between the two indices and HF, and different models were constructed by including different covariants. The results are presented as odds ratios (ORs). Additionally, 95% confidence intervals (95% CI) were calculated. Continuous and categorical forms of TyG and TyG-WC were used as variables to construct the models. Model 1 did not incorporate any adjustment factors, whereas model 2 integrated demographic covariates, including age, sex, race, education, and income. Model 3 incorporated cardiovascular diseases that are risk factors for HF. Model 4 incorporated all covariates in models 2 and 3 as adjustment factors, including age, sex, race, education, income, and associated cardiovascular diseases.

After generating the models, a subgroup analysis was used to explore the factors that might influence the association between the TyG or TyG-WC index and HF. The study participants were divided into two groups

according to BMI. Multivariable logistic regression analysis was used to construct models with the TyG or TyG-WC index and HF risk for each group. Each group consisted of four models with adjustment factors applied as previously described.

Next, restricted cubic splines (RCS) were employed to explore the linear relationships between HF risk and the two indices. The nodes were selected as tertiles and the thresholds are marked in the figures. After that, the receiver operating characteristic (ROC) was used to compare the efficacy of the different models using the area under the curve (AUC). NRI and IDI were used to compare the efficacies of the four models of the two indices. The new models were established as the TyG-WC models. When the NRI or IDI was positive and the *P*-value was less than 0.05, the efficacy of the TyG-WC model was superior.

Results

Characteristics of baseline data of study subjects

Differences in multiple variables between the groups were analyzed to assess the baseline characteristics of the 8769 study participants.

Regarding HF, 8503 individuals did not have HF, whereas 266 did (Table 1). The HF group was older and had lower educational and income levels than the group without HF. Compared to participants without HF, participants with HF had a higher weight, BMI, fasting glucose level, triglyceride level, WC, glycosylated hemoglobin (HbA1c) level, and lower high-density lipoprotein (HDL) level. Notably, low-density lipoprotein (LDL) and total cholesterol (TC) levels were lower in the HF group, likely because the patients with HF were prescribed statins, which effectively controlled their LDL and TC levels. The number of patients with diabetes, myocardial infarction, hypertension, coronary artery disease, angina, or stroke was higher in the HF group. Moreover, the TyG and TyG-WC indices were significantly higher in the HF group.

When using the TyG index tertiles as categorical indicators (Table 2), the higher the TyG index, the older the study participants. In addition, the percentage of individuals with diabetes, myocardial infarction, hypertension, coronary heart disease, angina, and stroke was higher among those with an increased TyG index. When the TyG-WC index tertiles were used as categorical indicators (Table 3), the results were similar to those of the TyG index. The percentage of patients with HF increased with increasing TyG and TyG-WC indices.

Analysis of the baseline data demonstrated that patients with HF often had metabolic abnormalities. Both indices were higher in patients with HF, suggesting that they may be strongly associated with HF.

Relationships between the TyG index, TyG-WC index, and HF

As explained in the methods section, multivariable logistic regression was used to create models and calculate the ORs of the two indices for HF.

For the continuous TyG index in Model 1, with no variable adjustment, there was a positive association between the index and HF (OR, 1.765; 95% CI, 1.390–2.242; $P < 0.001$). The results were similar in model 2 after adjusting for demographic variables (OR, 1.385, 95% CI, 1.055–1.817, $P < 0.05$) and in model 3 after adjusting for comorbidities (OR, 1.308, 95% CI, 1.018–1.681, $P < 0.05$). However, in model 4, which was adjusted for all variables, the results were not statistically significant (OR, 1.238; 95%CI, 0.941–1.629; $P = 0.124$). The categorical form was further analyzed, with the lowest tertile used as the reference. In the middle tertile, the ORs were not significantly higher in any of the four models. However, at the highest tertile, ORs were significantly increased in model 1 (OR, 2.518, 95% CI, 1.661–3.818, $P < 0.001$), model 2 (OR, 1.606, 95% CI, 1.061–2.431, $P < 0.05$) and model 3 (OR, 1.739, 95% CI, 1.110–2.725, $P < 0.0$). The ORs of model 4 in the highest tertile were higher than those in the middle tertile; however, the trend was not significant (OR, 1.487; 95% CI, 0.966–2.290; $P = 0.0709$). The results are presented as a forest plot (Fig. 2).

For continuous TyG-WC index, the index was positively associated with HF in model 1 (OR, 1.003, 95% CI, 1.002–1.004, $P < 0.001$), model 2 (OR, 1.003; 95% CI, 1.001–1.004, $P < 0.001$), model 3 (OR, 1.308, 95% CI, 1.018–1.681, $P < 0.05$) and model 4 (OR, 1.002, 95% CI, 1.001–1.004, $P < 0.001$). Next, we examined the association between the TyG-WC index and the risk of HF according to the TyG-WC tertiles. The first (lowest) tertile was used as the reference. In the middle tertile, the change in the OR was not significant for any of the four models. However, ORs were significantly higher for the highest TyG-WC tertile compared to the lower tertiles in model 1 (OR, 2.885, 95% CI, 1.892–4.401, $P < 0.001$), model 2 (OR, 1.694, 95% CI, 1.107–2.594, $P < 0.05$), model 3 (OR, 1.888, 95% CI, 1.245–2.862, $P < 0.05$) and model 4 (OR, 1.664, 95% CI, 1.087–2.548, $P < 0.05$). The results are presented as a forest plot (Fig. 3).

Analysis of subgroups with different BMIs

Subgroup analysis was used to assess possible variables affecting the association between the TyG index or TyG-WC index and HF. The results are shown in the two forest plots (Figs. 4 and 5). Race was an interaction factor for the two indices (*P* for interaction of the TyG index, 0.012; *P* for interaction of the TyG-WC index, 0.005), and education was an interaction factor for the TyG index (*P* for interaction of the TyG index, 0.022). BMI was not

Table 1 Baseline characteristics categorized by the presence or absence of HF

Variables	Overall N = 8769 (100%)	Non-Heart Failure N = 8503 (98%)	Heart Failure N = 266 (2.3%)	*P*-Value
Age(median [IQR])	47.0 (33.0, 61.0)	47.0 (33.0, 60.0)	68.0 (58.8, 75.0)	<0.001
Sex(%)				0.524
Male	4,234 (48.5%)	4,090 (48.4%)	144 (51.4%)	
Female	4,535 (51.5%)	4,413 (51.6%)	122 (48.6%)	
Race(%)				0.108
Mexican American	1,136 (8.3%)	1,114 (8.3%)	22 (4.5%)	
Other Hispanic	926 (6.3%)	899 (6.3%)	27 (4.4%)	
Non-Hispanic White	3,408 (67.2%)	3,265 (67.0%)	143 (73.5%)	
Non-Hispanic Black	1,881 (9.7%)	1,821 (9.7%)	60 (11.8%)	
Other Race-Including Multi-Racial	1,418 (8.6%)	1,404 (8.7%)	14 (5.7%)	
Education(%)				<0.001
Less than high school	1,743 (13.0%)	1,665 (12.8%)	78 (23.5%)	
High school	1,937 (22.1%)	1,859 (21.8%)	78 (32.8%)	
More than high school	5,089 (64.9%)	4,979 (65.4%)	110 (43.6%)	
Income(%)				<0.001
Low	7,183 (73.3%)	6,937 (72.8%)	246 (91.6%)	
High	1,586 (26.7%)	1,566 (27.2%)	20 (8.4%)	
Weight(median [IQR])	80.7 (68.2, 95.2)	80.6 (68.2, 94.9)	83.8 (71.3, 104.7)	<0.05
Height_m(median [IQR])	1.7 (1.6, 1.8)	1.7 (1.6, 1.8)	1.7 (1.6, 1.7)	0.055
BMI(median [IQR])	28.1 (24.3, 32.7)	28.0 (24.3, 32.6)	30.6 (25.6, 36.3)	<0.05
BMI_factor(%)				<0.05
<25kg/m^2	2,521 (28.4%)	2,468 (28.6%)	53 (20.6%)	
⩾25kg/m^2	6,248 (71.6%)	6,035 (71.4%)	213 (79.4%)	
FDG(median [IQR])	100.0 (94.0, 109.0)	100.0 (94.0, 109.0)	108.0 (98.0, 126.0)	<0.001
TG(median [IQR])	94.0 (65.0, 140.0)	94.0 (65.0, 139.0)	113.0 (78.0, 154.7)	<0.05
TyG(median [IQR])	8.5 (8.1, 8.9)	8.5 (8.1, 8.9)	8.8 (8.3, 9.2)	<0.001
TyG_factor(%)				<0.001
Q1-TyG	2,923 (33.4%)	2,862 (33.7%)	61 (20.5%)	
Q2-TyG	2,921 (33.3%)	2,835 (33.4%)	86 (29.0%)	
Q3-TyG	2,925 (33.3%)	2,806 (32.9%)	119 (50.4%)	
Waistline(median [IQR])	98.4 (88.0, 109.7)	98.2 (87.8, 109.4)	108.9 (95.9, 120.1)	<0.001
TyG-WC(median [IQR])	843.4 (721.6, 963.8)	841.5 (720.3, 960.1)	943.5 (796.5, 1,104.4)	<0.001
TyG_WC_factor(%)				<0.001
Q1-TyG-WC	2,923 (33.0%)	2,874 (33.3%)	49 (19.4%)	
Q2-TyG-WC	2,923 (32.8%)	2,853 (33.1%)	70 (24.1%)	
Q3-TyG-WC	2,923 (34.2%)	2,776 (33.6%)	147 (56.5%)	
LDL(median [IQR])	110.0 (88.0, 135.0)	110.0 (88.0, 135.0)	92.0 (74.0, 117.0)	<0.001
HbA1c(median [IQR])	5.4 (5.2, 5.8)	5.4 (5.2, 5.7)	5.9 (5.5, 6.3)	<0.001
HDL(median [IQR])	52.0 (43.0, 63.0)	52.0 (43.0, 63.0)	46.0 (39.0, 56.0)	<0.001
TC(median [IQR])	186.0 (161.0, 214.0)	187.0 (161.0, 214.0)	165.2 (143.6, 199.0)	<0.001
Diabetes(%)	1,213 (10.2%)	1,108 (9.7%)	105 (32.5%)	<0.001
Hypertension(%)	3,128 (31.9%)	2,921 (30.9%)	207 (76.3%)	<0.001
Coronary heart disease(%)	321 (3.2%)	220 (2.4%)	101 (38.2%)	<0.001
Angina(%)	184 (1.9%)	129 (1.4%)	55 (21.5%)	<0.001
Heart attack(%)	329 (3.0%)	222 (2.1%)	107 (39.4%)	<0.001
Stroke(%)	327 (3.0%)	266 (2.5%)	61 (22.8%)	<0.001

an interacting factor that could affect the association between the two indices and HF.

However, the TyG index was constructed primarily for normal individuals without considering the effect of nutritional status on metabolism. Low lipid and blood glucose levels are typically associated with malnutrition. Therefore, a high TyG level in a person with a low BMI may indicate good nutritional status. Using the TyG index alone to construct models for all participants may not be sufficiently accurate [15]. To further explore the

Table 2 Baseline characteristics (categorized by TyG index tertiles)

Variables	Overall N = 8769 (100%)	Q1-TyG N = 2923 (33%)	Q2-TyG N = 2921 (33%)	Q3-TyG N = 2925 (33%)	*P*-value
Age(median [IQR])	47.0 (33.0, 61.0)	40.0 (28.0, 55.0)	48.0 (34.0, 61.0)	53.0 (40.0, 64.0)	<0.001
Sex(%)					<0.001
Male	4,234 (48.5%)	1,175 (41.2%)	1,459 (48.9%)	1,600 (55.4%)	
Female	4,535 (51.5%)	1,748 (58.8%)	1,462 (51.1%)	1,325 (44.6%)	
Race(%)					<0.001
Mexican American	1,136 (8.3%)	268 (6.5%)	385 (8.4%)	483 (9.9%)	
Other Hispanic	926 (6.3%)	246 (5.6%)	321 (6.7%)	359 (6.4%)	
Non-Hispanic White	3,408 (67.2%)	1,026 (64.4%)	1,158 (68.1%)	1,224 (69.0%)	
Non-Hispanic Black	1,881 (9.7%)	913 (15.0%)	590 (8.6%)	378 (5.6%)	
Other Race-Including Multi-Racial	1,418 (8.6%)	470 (8.5%)	467 (8.2%)	481 (9.0%)	
Education(%)					<0.001
Less than high school	1,743 (13.0%)	434 (9.5%)	589 (14.0%)	720 (15.6%)	
High school	1,937 (22.1%)	622 (20.4%)	636 (20.8%)	679 (25.0%)	
More than high school	5,089 (64.9%)	1,867 (70.1%)	1,696 (65.2%)	1,526 (59.4%)	
Income(%)					<0.05
Low	7,183 (73.3%)	2,346 (71.3%)	2,385 (72.6%)	2,452 (75.9%)	
High	1,586 (26.7%)	577 (28.7%)	536 (27.4%)	473 (24.1%)	
Weight(median [IQR])	80.7 (68.2, 95.2)	72.3 (62.4, 86.0)	80.7 (68.7, 94.2)	88.5 (76.1, 102.5)	<0.001
Height_m(median [IQR])	1.7 (1.6, 1.8)	1.7 (1.6, 1.8)	1.7 (1.6, 1.8)	1.7 (1.6, 1.8)	0.131
BMI(median [IQR])	28.1 (24.3, 32.7)	25.4 (22.5, 29.4)	28.0 (24.8, 32.2)	30.8 (27.1, 35.4)	<0.001
BMI_factor(%)					<0.001
< 25kg/m^2	2,521 (28.4%)	1,285 (46.4%)	796 (25.9%)	440 (12.9%)	
≥25kg/m^2	6,248 (71.6%)	1,638 (53.6%)	2,125 (74.1%)	2,485 (87.1%)	
FDG(median [IQR])	100.0 (94.0, 109.0)	95.0 (90.0, 101.0)	100.0 (94.0, 107.0)	109.0 (100.0, 125.0)	<0.001
TG(median [IQR])	94.0 (65.0, 140.0)	56.0 (44.0, 66.0)	95.0 (84.1, 110.0)	166.0 (139.0, 214.0)	<0.001
Waistline(median [IQR])	98.4 (88.0, 109.7)	90.1 (81.1, 100.8)	98.3 (88.8, 108.5)	106.1 (97.1, 117.0)	<0.001
TyG-WC(median [IQR])	843.4 (721.6, 963.8)	705.9 (632.1, 798.3)	836.8 (756.1, 923.5)	978.1 (890.2, 1,084.6)	<0.001
TyG_WC_factor(%)					<0.001
Q1-TyG-WC	2,923 (33.0%)	1,935 (67.3%)	816 (26.8%)	172 (4.8%)	
Q2-TyG-WC	2,923 (32.8%)	716 (24.6%)	1,313 (46.5%)	894 (27.5%)	
Q3-TyG-WC	2,923 (34.2%)	272 (8.1%)	792 (26.7%)	1,859 (67.8%)	
LDL(median [IQR])	110.0 (88.0, 135.0)	98.0 (80.0, 120.0)	114.0 (94.0, 138.0)	118.0 (92.0, 145.0)	<0.001
HbA1c(median [IQR])	5.4 (5.2, 5.8)	5.3 (5.1, 5.5)	5.4 (5.2, 5.7)	5.7 (5.4, 6.2)	<0.001
HDL(median [IQR])	52.0 (43.0, 63.0)	60.0 (51.0, 72.0)	53.0 (45.0, 63.0)	44.0 (38.0, 52.0)	<0.001
TC(median [IQR])	186.0 (161.0, 214.0)	172.0 (151.0, 196.0)	190.0 (164.6, 215.0)	199.4 (172.0, 229.0)	<0.001
Diabetes(%)	1,213 (10.2%)	143 (2.8%)	287 (6.3%)	783 (21.6%)	<0.001
Hypertension(%)	3,128 (31.9%)	747 (20.2%)	998 (30.7%)	1,383 (44.9%)	<0.001
Heart failure(%)	266 (2.3%)	61 (1.4%)	86 (2.0%)	119 (3.5%)	<0.001
Coronary heart disease(%)	321 (3.2%)	68 (2.1%)	110 (3.2%)	143 (4.4%)	<0.001
Angina(%)	184 (1.9%)	42 (1.2%)	58 (1.7%)	84 (2.8%)	<0.05
Heart attack(%)	329 (3.0%)	71 (1.7%)	117 (3.3%)	141 (3.9%)	<0.001
Stroke(%)	327 (3.0%)	87 (2.1%)	115 (3.1%)	125 (3.6%)	<0.05

efficacy of the two indices in reflecting the occurrence of HF in individuals with varying BMI, the study population was grouped according to BMI. The World Health Organization (WHO) categorized people as normal or thin (BMI < 25 kg/m^2) and overweight or obese (BMI ≥ 25 kg/m^2). Using a cutoff of 25 kg/m^2, each group consisted of four models, with adjustment factors applied as previously described. The ORs between the indices and HF were calculated separately.

Among overweight or obese individuals, the ORs of the continuous TyG and TyG-WC indices were greater than 1 in all four models. When analyzing the categorical forms, the ORs of the middle tertile were not significantly increased in any of the four models compared with the reference tertile; however, in the highest tertile, the ORs were the highest. This indicates that the higher the TyG and TyG-WC indices, the higher the risk of HF in overweight or obese individuals. The statistical results are presented in Tables 4 and 5.

However, the associations among TyG, TyG-WC, and HF differed between normal and thin individuals. The OR of the continuous TyG index and HF was significant only in model 4, and the OR was less than 1 (OR, 0.406; 95% CI, 0.175–0.944; $P < 0.05$). Analysis of categorical TyG revealed that most of the results were not significant; however, the ORs gradually decreased or increased with decreasing or increasing TyG indices across the different models. This suggests that for normal or underweight populations, the risk of HF might be reduced with a high TyG index.

Table 3 Baseline characteristics (categorized by TyG-WC index tertiles)

Variables	Overall N = 8769 (100%)	Q1-TyG-WC N = 2923 (33%)	Q2-TyG-WC N = 2923 (33%)	Q3-TyG-WC N = 2923 (34%)	*P*-value
Age(median [IQR])	47.0 (33.0, 61.0)	39.0 (27.0, 55.0)	49.0 (36.0, 62.0)	52.0 (39.0, 63.8)	<0.001
Sex(%)					<0.001
Male	4,234 (48.5%)	1,158 (38.0%)	1,522 (51.9%)	1,554 (55.3%)	
Female	4,535 (51.5%)	1,765 (62.0%)	1,401 (48.1%)	1,369 (44.7%)	
Race(%)					<0.001
Mexican American	1,136 (8.3%)	259 (6.4%)	438 (9.4%)	439 (8.9%)	
Other Hispanic	926 (6.3%)	266 (6.3%)	337 (6.8%)	323 (5.7%)	
Non-Hispanic White	3,408 (67.2%)	1,016 (63.5%)	1,075 (66.5%)	1,317 (71.3%)	
Non-Hispanic Black	1,881 (9.7%)	659 (11.0%)	605 (9.3%)	617 (8.9%)	
Other Race-Including Multi-Racial	1,418 (8.6%)	723 (12.7%)	468 (8.1%)	227 (5.2%)	
Education(%)					<0.001
Less than high school	1,743 (13.0%)	470 (10.6%)	618 (14.0%)	655 (14.5%)	
High school	1,937 (22.1%)	584 (19.2%)	639 (21.7%)	714 (25.1%)	
More than high school	5,089 (64.9%)	1,869 (70.2%)	1,666 (64.3%)	1,554 (60.4%)	
Income(%)					<0.001
Low	7,183 (73.3%)	2,311 (70.4%)	2,373 (72.0%)	2,499 (77.2%)	
High	1,586 (26.7%)	612 (29.6%)	550 (28.0%)	424 (22.8%)	
Weight(median [IQR])	80.7 (68.2, 95.2)	64.8 (57.8, 71.9)	80.7 (73.2, 89.3)	100.2 (89.1, 113.4)	<0.001
Height_m(median [IQR])	1.7 (1.6, 1.8)	1.7 (1.6, 1.7)	1.7 (1.6, 1.8)	1.7 (1.6, 1.8)	<0.001
BMI(median [IQR])	28.1 (24.3, 32.7)	23.3 (21.3, 25.2)	28.1 (26.2, 30.6)	34.3 (30.9, 39.0)	<0.001
BMI_factor(%)					<0.001
<25kg/m^2	2,521 (28.4%)	2,058 (71.7%)	435 (13.5%)	28 (1.1%)	
≥25kg/m^2	6,248 (71.6%)	865 (28.3%)	2,488 (86.5%)	2,895 (98.9%)	
FDG(median [IQR])	100.0 (94.0, 109.0)	95.0 (90.0, 101.0)	100.0 (94.0, 107.0)	108.0 (100.0, 123.0)	<0.001
TG(median [IQR])	94.0 (65.0, 140.0)	63.0 (47.0, 84.8)	97.0 (73.0, 129.0)	140.0 (101.0, 194.0)	<0.001
TyG(median [IQR])	8.5 (8.1, 8.9)	8.0 (7.7, 8.3)	8.5 (8.2, 8.8)	9.0 (8.6, 9.4)	<0.001
TyG_factor(%)					<0.001
Q1-TyG	2,923 (33.4%)	1,935 (68.1%)	716 (25.0%)	272 (8.0%)	
Q2-TyG	2,921 (33.3%)	816 (27.1%)	1,313 (47.2%)	792 (26.1%)	
Q3-TyG	2,925 (33.3%)	172 (4.8%)	894 (27.8%)	1,859 (66.0%)	
Waistline(median [IQR])	98.4 (88.0, 109.7)	83.5 (78.3, 88.5)	98.3 (94.5, 103.2)	114.7 (108.1, 123.9)	<0.001
LDL(median [IQR])	110.0 (88.0, 135.0)	100.0 (81.0, 123.0)	115.0 (95.0, 141.0)	113.0 (89.0, 137.0)	<0.001
HbA1c(median [IQR])	5.4 (5.2, 5.8)	5.3 (5.1, 5.5)	5.4 (5.2, 5.7)	5.7 (5.4, 6.2)	<0.001
HDL(median [IQR])	52.0 (43.0, 63.0)	61.0 (52.0, 73.0)	52.0 (44.0, 62.0)	44.0 (38.0, 52.0)	<0.001
TC(median [IQR])	186.0 (161.0, 214.0)	179.0 (155.0, 204.0)	192.0 (166.0, 219.0)	190.0 (163.0, 218.0)	<0.001
Diabetes(%)	1,213 (10.2%)	107 (1.9%)	318 (6.6%)	788 (21.7%)	<0.001
Hypertension(%)	3,128 (31.9%)	558 (16.0%)	1,057 (30.8%)	1,513 (48.4%)	<0.001
Heart failure(%)	266 (2.3%)	49 (1.3%)	70 (1.7%)	147 (3.8%)	<0.001
Coronary heart disease(%)	321 (3.2%)	58 (2.1%)	108 (3.1%)	155 (4.4%)	<0.001
Angina(%)	184 (1.9%)	27 (1.1%)	64 (1.6%)	93 (2.9%)	<0.05
Heart attack(%)	329 (3.0%)	58 (1.7%)	114 (2.8%)	157 (4.3%)	<0.001
Stroke(%)	327 (3.0%)	76 (2.1%)	108 (2.9%)	143 (3.8%)	<0.05

ORs of the continuous TyG-WC index were greater than 1 in model 1 and the result was significant (OR, 1.006; 95% CI, 1.003–1.008; $P<0.001$). Analysis of the categorical TyG-WC index revealed that although most results were not statistically significant, unlike the TyG index, the ORs increased when the TyG-WC index increased. This indicates that for normal or underweight individuals, the risk of HF increased as TyG-WC increased. The results are summarized in Table 5. results.

Analysis of RCS plots

RCS plots were used to assess the linear or nonlinear relationships between the two indices and HF (Figs. 6 and 7). In the baseline analysis, tertiles were chosen for categorization to reduce errors in the results for certain indicators. Therefore, when selecting the knots for the RCS plots, tertiles were selected as the three knots that were consistent with the baseline analysis.

The relationship between TyG and HF was linear only in models 1 and 3 (model 1, $P=0.7454$; model 3, $P=0.3021$). In models 2 and 4, the curves were J-and U-shaped, respectively. In model 4, the ORs for individuals who were normal or underweight decreased slightly, initially falling below 1. This trend indicates that the risk of HF decreased with increasing TyG when the BMI was < 25 kg/m2. In contrast, the ORs for overweight or obese individuals were greater than 1 and increased as the TyG index increased.

The relationship between TyG-WC and HF was linear in models 1, 3, and 4 (model 1, $P=0.1594$; model 3, $P=0.7080$; and model 4, $P=0.0539$). In model 4, the ORs increased as the TyG-WC index increased across all BMI

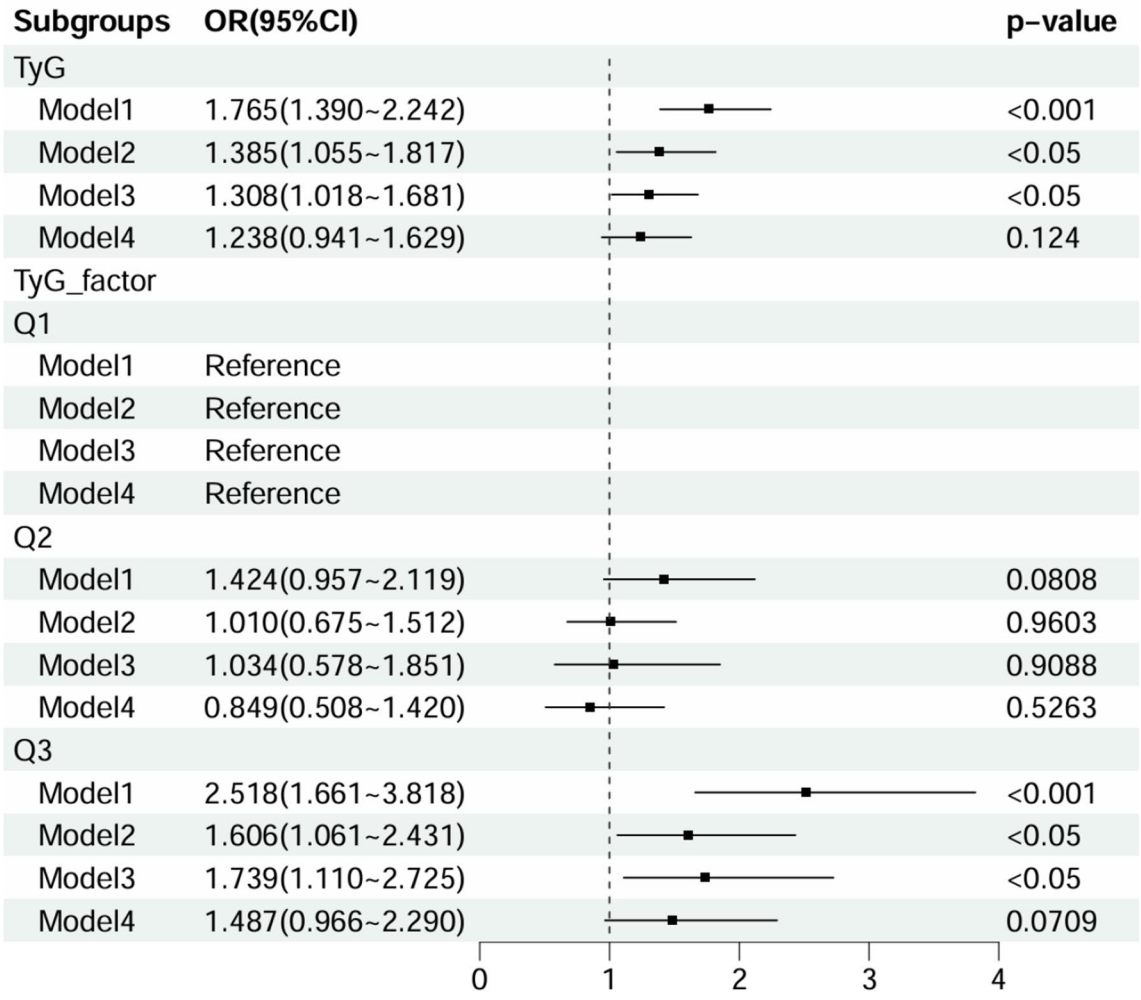

Fig. 2 Forest plot of associations between the TyG index and HF

levels and were all greater than 1. This trend indicates that HF risk increased with increasing TyG-WC.

Using ROC, NRI, and IDI to compare models

The efficacy of the four models of the two indices was also measured using the AUC of the ROC and by calculating the cutoff value (Fig. 8). The AUC of the TyG index (continuous) was significant in models 2, 3, and 4 in normal and thin individuals (model 4: AUC, 0.9087; 95%CI, 0.8692–0.9482); however, the TyG index alone could not predict HF. The AUC calculated in the plot of the TyG-WC index (continuous) did not include 0.5 (significant) in all four models. The TyG-WC cut-off and sensitivity were 682.60%, 73.6%, and 53.8%, respectively.

In those with a BMI greater than or equal to 25 kg/m^2, the AUC calculated in the plot of the TyG index (continuous) did not include 0.5 (significant) in all four models. The cutoff value was 8.78 (sensitivity, 51.2%; specificity, 61.6%). The AUC of the TyG-WC index (continuous) was significant in all the four models. The TyG-WC index cut-off was 1055.692, with a sensitivity of 41.8% and specificity of 41.8% and 82.8%, respectively. Among all the models, model 4 had the highest efficacy.

Results from the NRI and IDI supported that the TyG index alone was not as effective as the TyG-WC index to show an association with HF in normal or underweight populations and should be combined with other variations (Table 6), similar to the result from ROC. The TyG index exceeded the TyG-WC index in terms of the efficacy of the model adjusted for all covariates. In overweight and obese populations, the TyG-WC index showed a stronger association than TyG in all models. However, ROC and AUC analyses revealed that TyG-WC had a lower sensitivity when used alone (41.8%), based on its cutoff value.

Discussion

Based on the results, nutritional indices should be considered when analyzing their association with HF. Zhao et al. [16] suggested that the Nutritional Metabolic Risk

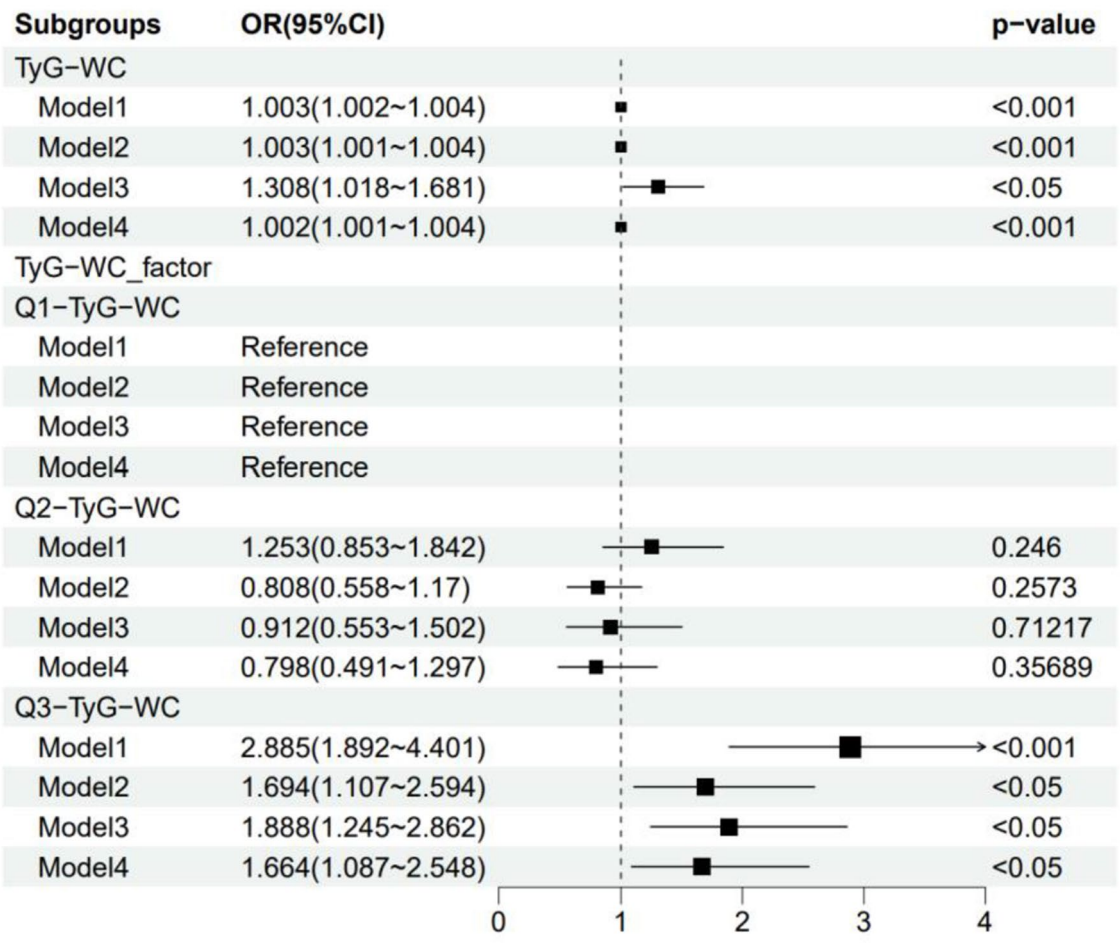

Fig. 3 Forest plot of associations between the TyG-WC index and HF

Index could predict all-cause mortality in Americans. The better the nutritional status, the lower the risk of mortality. Another team from Japan [17] designed the ALIMENT-HF trial to assess the type of dietary supplements that could benefit outpatients. Thus, nutritional status is important and has garnered considerable attention.

BMI was used as a reference in this study. In the underweight and normal populations, the RCS curves suggested that the TyG index could protect people from HF within a certain range, and the curves were either U- or J-shaped. The ROC curves suggested that the TyG index alone was not associated with HF. Jiang et al. [18] suggested that when analyzing populations with malnutrition, a U-shaped relationship was observed in the RCS curves of TyG and HF. Furthermore, ROC, NRI, and IDI analyses suggested that TyG-WC alone may be better associated with HF when individuals are lean or of normal weight and that adjusting for demographics and comorbidities could help both indices predict HF accurately. Therefore, considering the TyG index and WC together could more accurately assess the risk of HF in individuals with a lower BMI.

In the overweight and obese populations, the ROC curves suggested that both indices had high efficacy after adjusting for confounders. Based on the NRI and IDI results, the TyG-WC index exceeded the TyG index in association with HF. However, the TyG-WC index in model 1 had a sensitivity of only 41.8%, suggesting that TyG-WC should not be used alone to demonstrate an association with HF.

WC was used as a complementary indicator to the TyG index, because WC measurements may assess obesity more accurately than the TyG index alone. Traditional methods of determining obesity using BMI alone may overlook the effects of fat distribution. Abdominal obesity is characterized by high levels of visceral fat. The WHO criteria considered an adult male with a WC of 90 cm or more or an adult female with a WC of 85 cm or more to have abdominal obesity [19]. Sherf-Dagan et al. [20] suggested that when selecting candidates for obesity treatment, emphasis should be placed on fat mass

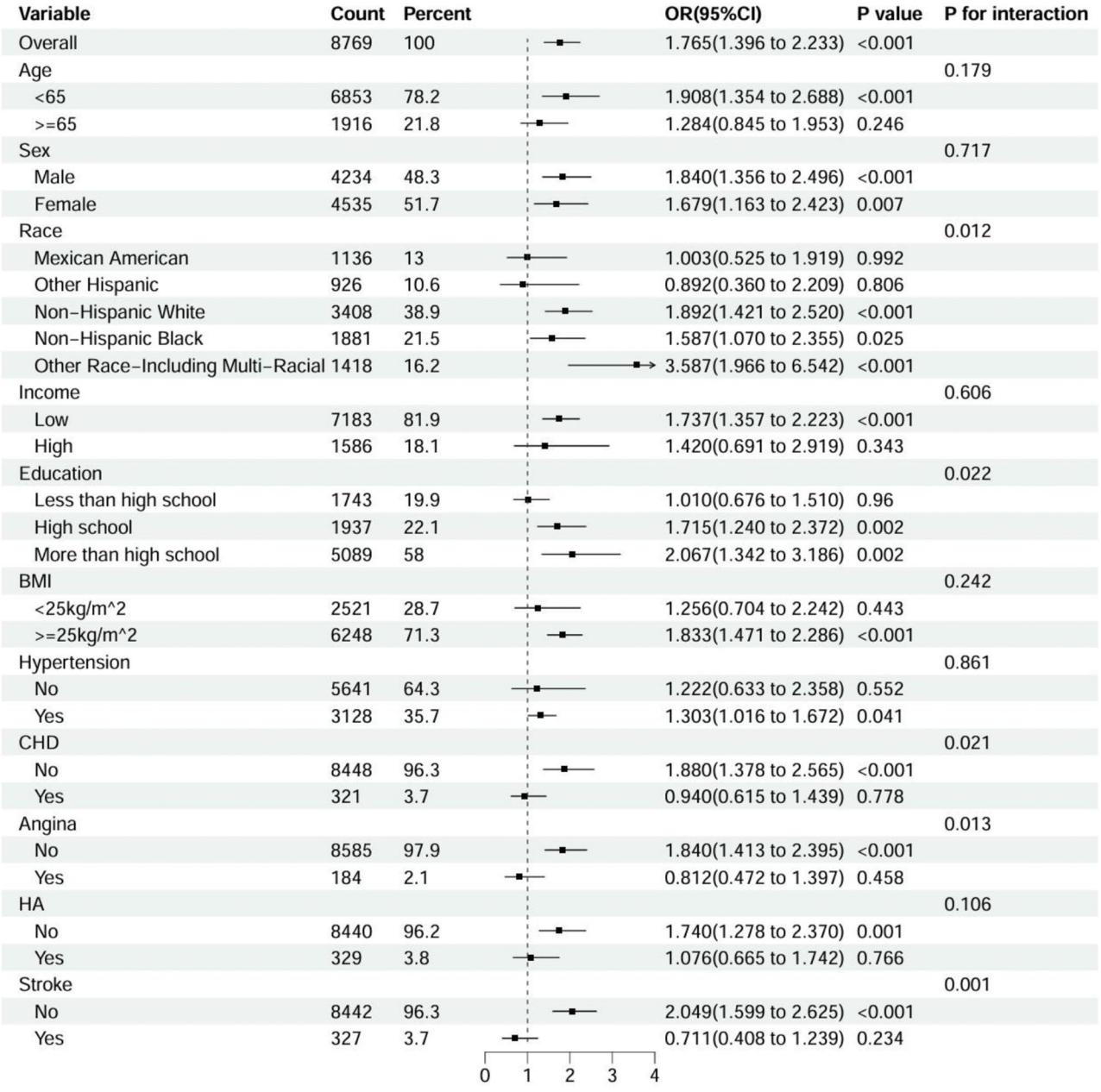

Fig. 4 Results of subgroup analysis of associations between the TyG index and HF

percentage and WC for diagnosing obesity rather than relying solely on BMI. Sweatt et al. [21] also demonstrated that while BMI is generally sufficient for diagnosing obesity, there are advantages to using WC to assess fat distribution. Therefore, fat metabolism should be considered while assessing glucose metabolism.

Other studies have demonstrated the value of TyG-WC and TyG indices. Khalaji et al. [22] included 30 studies in a systematic review with 772,809 participants. Compared to the lowest TyG group, the highest TyG group had a significantly increased risk of HF. The incidence of adverse events and mortality in patients were associated with TyG. Zheng et al. [23] used the NHANES database for their analysis, and the results showed that TyG, TyG-BMI, TyG-WC, and TyG-WHtR were significantly associated with chest pain. ROC curves showed that TyG-WC was the most robust and had the highest predictive value for coronary heart disease.

Glucose metabolism plays an important role in HF, and many recent studies have focused on it. Kato et al. [24] discovered that glucose metabolism could be improved by inhibiting the danamine-associated protein 1-fibronectin interaction and HF. Bei et al. [25] reported that inhibition of Hmbox1 in ischemia and reperfusion injury

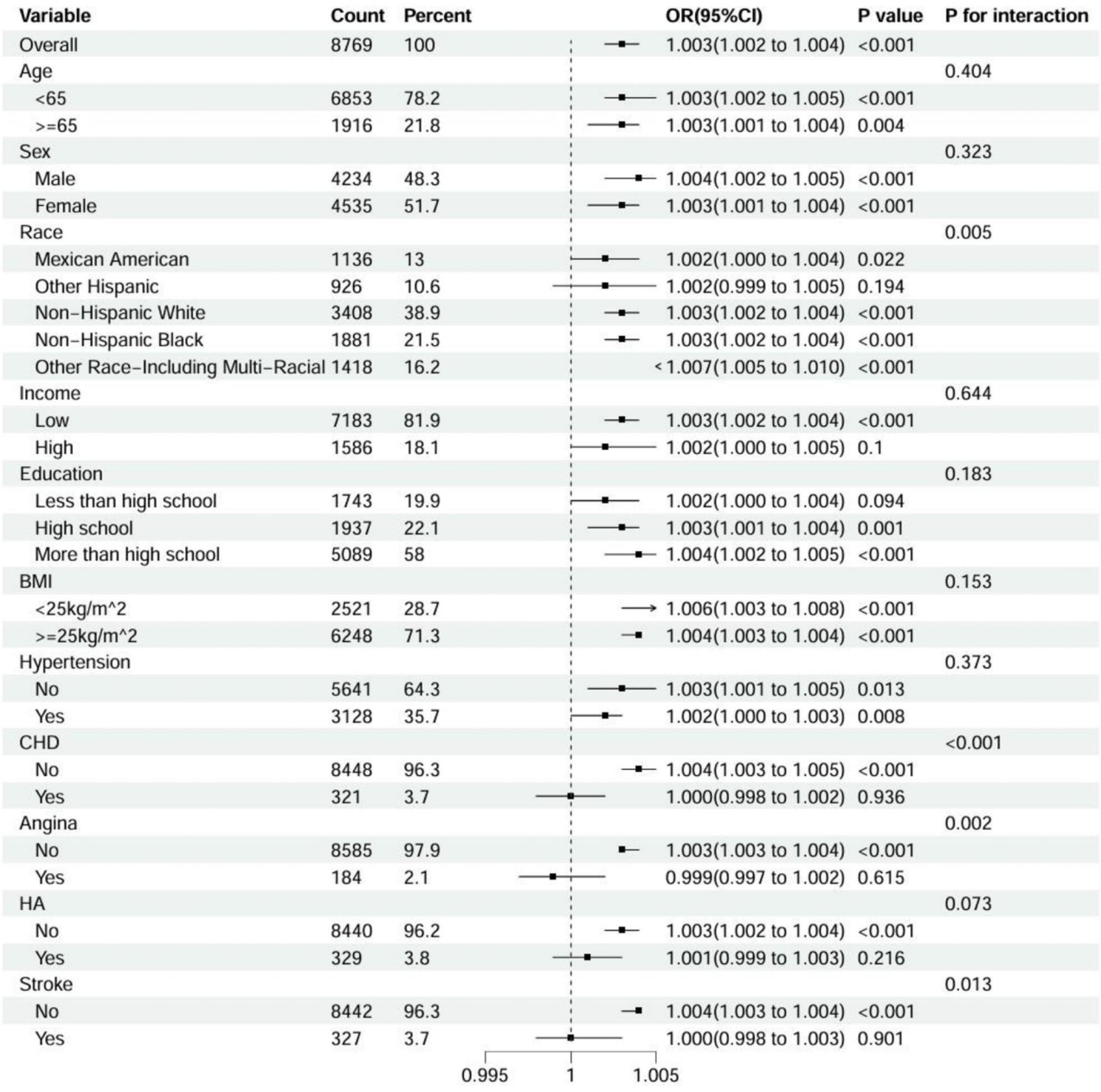

Fig. 5 Results of subgroup analysis of associations between the TyG-WC index and HF

promotes glucose metabolism and HF, providing evidence for the prevention of myocardial injury after ischemia/reperfusion. Other metabolic scores for insulin resistance have been shown to predict cardiovascular or cerebrovascular events in patients with hypertension. A one-unit increase in the insulin resistance metabolic score is associated with a 30% increase in the risk of CVD events and a 27% increase in the risk of stroke [26]. Only ischemic stroke was significantly associated with this score [27].

Strengths and limitations

This study has several strengths. First, the associations between TyG, TyG-WC, and HF were identified. Second, this study focused on the effects of BMI on these variables. Participants with a low BMI and a high TyG index might indicate that the nutritional status of the person was better. This study identified two indicators associated with HF in individuals with varying levels of obesity. Third, ROC, NRI, and IDI analyses were used to assess the efficacy of the models of the indices, thereby improving the accuracy of the analysis. Additionally, these results provide insights for clinicians in selecting indices

Table 4 Associations between the TyG index and HF at different BMI levels

	Subgroups	OR(95%CI)	*P*-value
TyG			
Model1	BMI<25kg/m^2	1.256(0.696~2.265)	0.4434
	BMI≥25kg/m^2	1.833(1.465~2.294)	<0.001
Model2	BMI<25kg/m^2	0.605(0.25~1.467)	0.2617
	BMI≥25kg/m^2	1.592(1.256~2.018)	<0.001
Model3	BMI<25kg/m^2	0.633(0.272~1.474)	0.28376
	BMI≥25kg/m^2	1.437(1.132~1.824)	<0.05
Model4	BMI<25kg/m^2	0.406(0.175~0.944)	<0.05
	BMI≥25kg/m^2	1.411(1.085~1.836)	<0.05
TyG_factor			
Q2			
Model1	BMI<25kg/m^2	2.588(1.124~5.956)	<0.05
	BMI≥25kg/m^2	1.022(0.634~1.647)	0.928
Model2	BMI<25kg/m^2	1.493(0.612~3.643)	0.3725
	BMI≥25kg/m^2	0.824(0.504~1.347)	
Model3	BMI<25kg/m^2	1.264(0.522~3.06)	0.59875
	BMI≥25kg/m^2	0.954(0.494~1.841)	0.88654
Model4	BMI<25kg/m^2	0.865(0.379~1.979)	0.7678
	BMI≥25kg/m^2	0.808(0.459~1.424)	0.4546
Q3			
Model1	BMI<25kg/m^2	1.228(0.493~3.059)	0.655
	BMI≥25kg/m^2	2.315(1.493~3.591)	<0.001
Model2	BMI<25kg/m^2	0.545(0.188~1.582)	0.2594
	BMI≥25kg/m^2	1.723(1.115~2.664)	<0.05
Model3	BMI<25kg/m^2	0.61(0.205~1.817)	0.36914
	BMI≥25kg/m^2	1.92(1.186~3.107)	<0.05
Model4	BMI<25kg/m^2	0.376(0.126~1.121)	0.0783
	BMI≥25kg/m^2	1.705(1.086~2.678)	<0.05

Table 5 Associations between the TyG-WC index and HF at different BMI levels

	Subgroups	OR(95%CI)	*P*-value
TyG-WC			
Model1	BMI<25kg/m^2	1.006(1.003~1.008)	<0.001
	BMI≥25kg/m^2	1.004(1.003~1.004)	<0.001
Model2	BMI<25kg/m^2	1(0.996~1.003)	0.89353
	BMI≥25kg/m^2	1.003(1.002~1.005)	<0.001
Model3	BMI<25kg/m^2	1.002(0.999~1.006)	0.17364
	BMI≥25kg/m^2	1.003(1.001~1.004)	<0.001
Model4	BMI<25kg/m^2	0.999(0.995~1.002)	0.44
	BMI≥25kg/m^2	1.003(1.001~1.004)	<0.001
TyG-WC_factor			
Q2			
Model1	BMI<25kg/m^2	1.766(0.801~3.897)	0.156
	BMI≥25kg/m^2	1.465(0.769~2.79)	0.242
Model2	BMI<25kg/m^2	0.778(0.363~1.669)	0.51409
	BMI≥25kg/m^2	0.97(0.505~1.863)	0.92554
Model3	BMI<25kg/m^2	0.844(0.303~2.348)	0.74198
	BMI≥25kg/m^2	1.13(0.462~2.764)	0.7861
Model4	BMI<25kg/m^2	0.58(0.194~1.732)	0.323
	BMI≥25kg/m^2	1.022(0.474~2.205)	0.9553
Q3			
Model1	BMI<25kg/m^2	2.818(0.608~13.067)	0.182
	BMI≥25kg/m^2	3.669(2.12~6.35)	<0.001
Model2	BMI<25kg/m^2	0.704(0.107~4.625)	0.4151
	BMI≥25kg/m^2	2.119(1.247~3.603)	<0.05
Model3	BMI<25kg/m^2	1.589(0.2~12.647)	0.65728
	BMI≥25kg/m^2	2.271(1.007~5.123)	<0.05
Model4	BMI<25kg/m^2	0.771(0.078~7.574)	0.8205
	BMI≥25kg/m^2	1.992(1.021~3.886)	<0.05

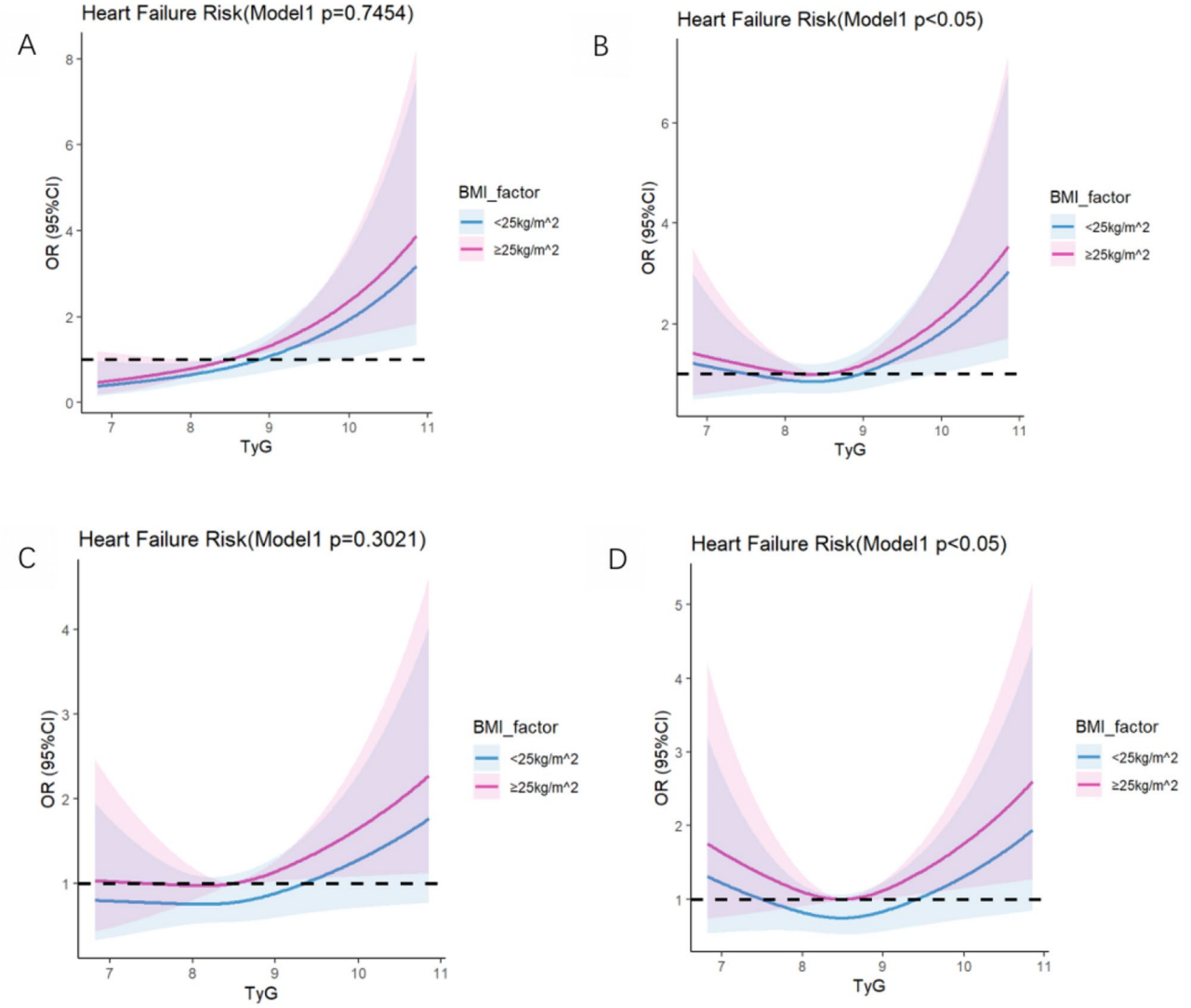

Fig. 6 Restricted cubic spline plots were used to assess the linear or nonlinear relationships between the TyG index and heart failure. Figures **A**, **B**, **C**, and **D** respectively showed the linear or nonlinear relationships between the TyG index and heart failure in Model 1, Model 2, Model 3, and Model 4

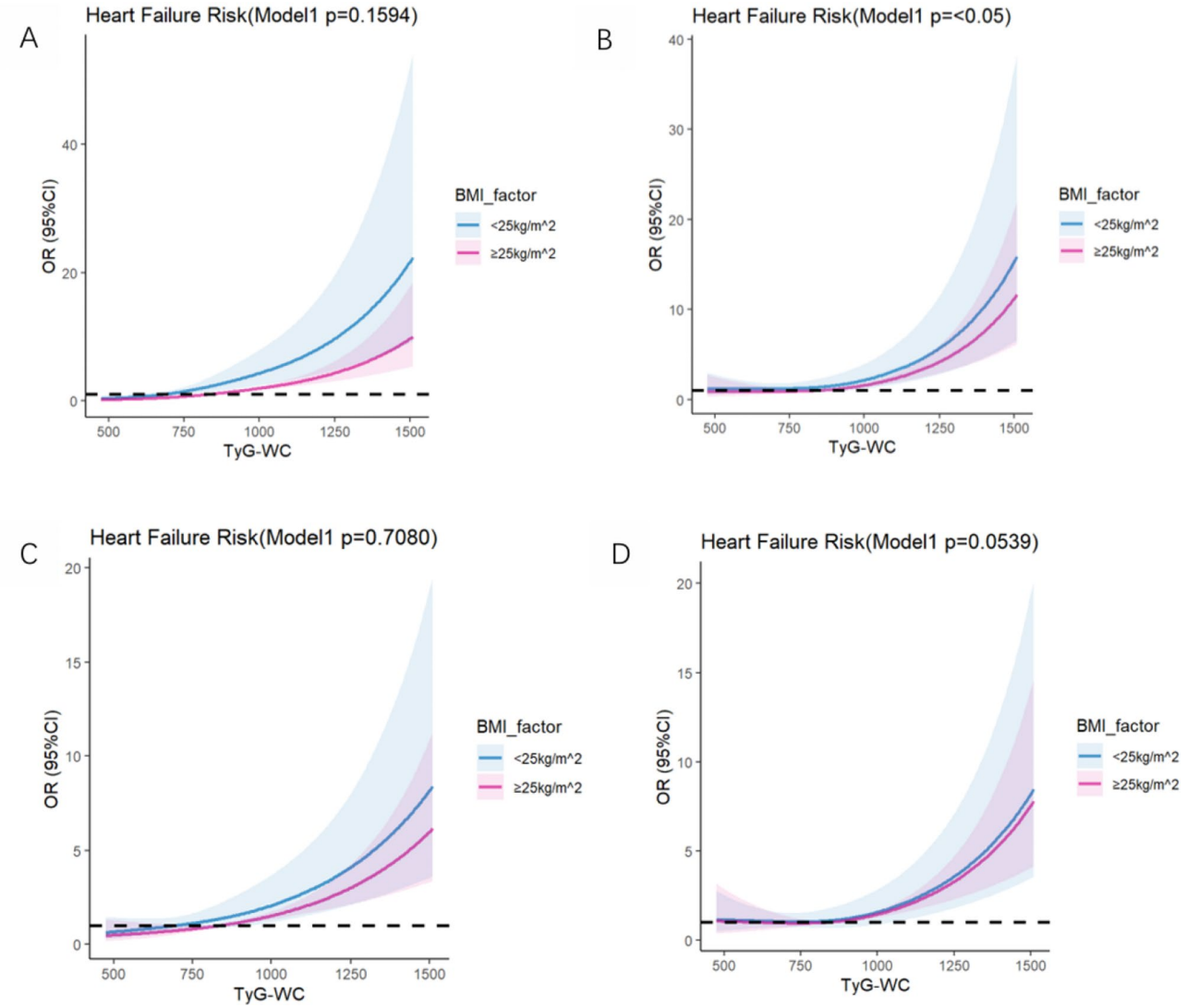

Fig. 7 Restricted cubic spline plots were used to assess the linear or nonlinear relationships between the TyG-WC index and heart failure. Figures **A**, **B**, **C**, and **D** respectively showed the linear or nonlinear relationships between the TyG-WC index and heart failure in Model 1, Model 2, Model 3, and Model 4

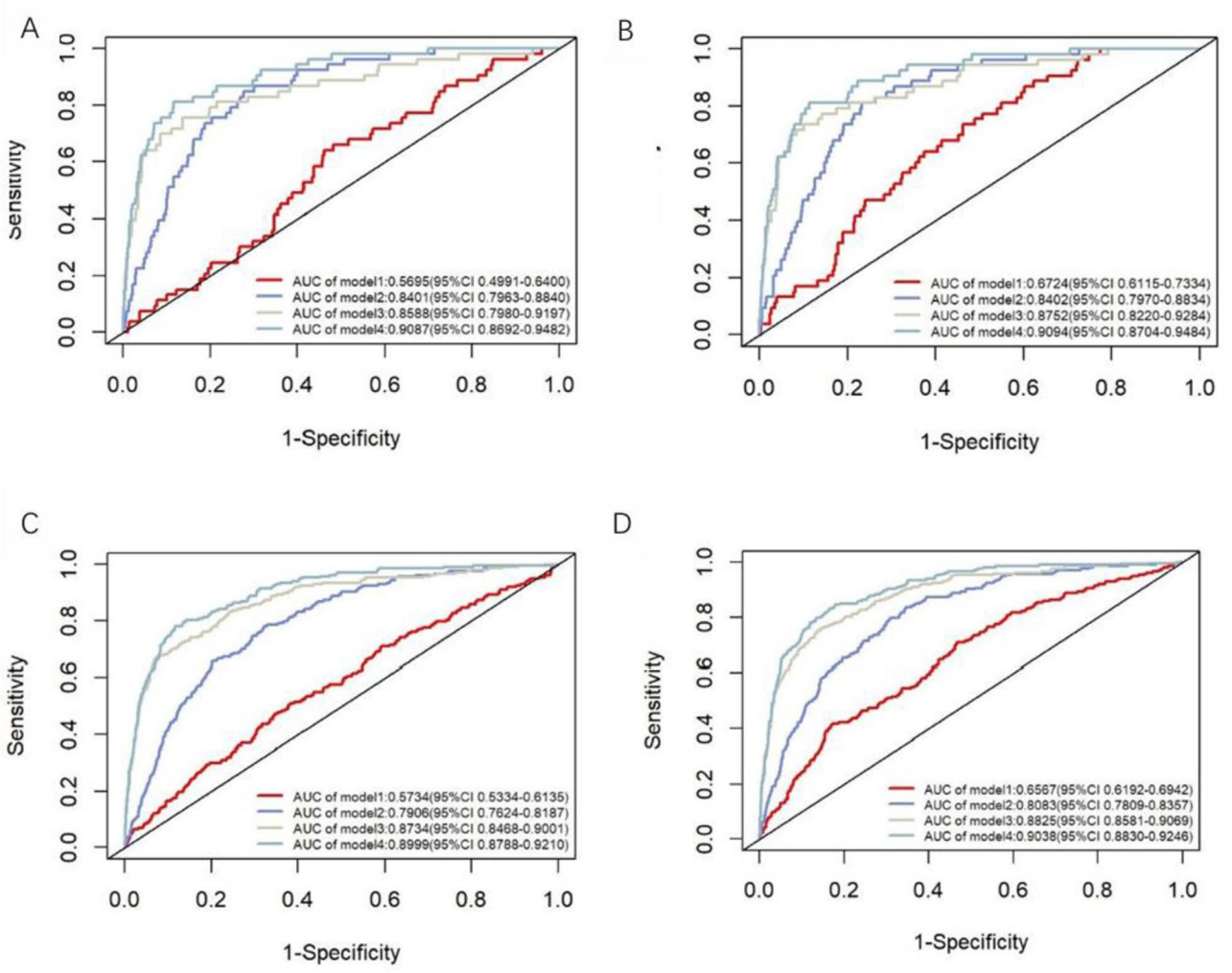

Fig. 8 ROC curves were used to assess the efficacy of models of the TyG and the TyG-WC index and calculate cutoff values. Figure A shows the ROC curves of the TyG index in four models for people with a BMI<25kg/m^2. Figure B shows the ROC curves of the TyG-WC index in four models for people with a BMI<25kg/m^2. Figure C shows the ROC curves of the TyG index in four models for people with a BMI 25kg/m⩾2. Figure D shows the ROC curves of the TyG-WC index in four models for people with BMI 25kg /m⩾2

to assess the risk of HF. The TyG index is a classic metabolic index that is a predictor of many clinically important diseases. The TyG index is an important reference for cardiovascular diseases.

This study has some limitations. First, as this was a cross-sectional study, it was impossible to determine the sequence of causes and consequences. Furthermore, exploring whether both indices can predict the prognosis of patients with HF remains challenging. Therefore, it would be better to consider time factors in this study. Second, potential confounders cannot be avoided in cross-sectional studies. Possible confounders were incorporated while constructing the models, thereby strengthening the validity of the findings. However, as the main aim of this study was to analyze the relationship between different indices and HF, possible interactions were not considered when constructing the models, and this study did not achieve the aim of training more accurate models. Additionally, the study sample was limited to the United

Table 6 Comparison of efficacy of the TyG and TyG-WC indices to show the association with HF (New models of NRI and IDI were four models of TyG-WC)

	ROC(TyG)			ROC(TyG-WC)		
	AUC[95%CI]	Sensitivity	Specificity	AUC[95%CI]	Sensitivity	Specificity
Subgroup1:BMI<25kg/m^2						
Model1	0.5695[0.4991-0.6400]	54%	64.20%	0.6724[0.6115-0.7334]	73.60%	53.80%
Model2	0.8401[0.7963-0.8840]	84.90%	72.30%	0.8402[0.797-0.8834]	81.10%	76.70%
Model3	0.8588[0.7980-0.9197]	75.50%	86.30%	0.8752[0.822-0.9284]	73.60%	90.00%
Model4	0.9087[0.8692-0.9482]	81.10%	88.50%	0.9094[0.8704-0.9484]	81.10%	88.70%
Subgroup2:BMI⩾25kg/m^2						
Model1	0.5734[0.5334-0.6135]	51.20%	61.60%	0.6724[0.6115-0.7334]	41.80%	82.80%
Model2	0.7906[0.7624-0.8187]	77.90%	67.90%	0.6567[0.6192-0.6942]	65.50%	83.60%
Model3	0.8734[0.8468-0.9001]	67.60%	92.40%	0.8825[0.8581-0.9069]	85.60%	76.10%
Model4	0.8999[0.8788-0.9210]	77.90%	88.40%	0.9038[0.883-0.9246]	82.10%	84.50%

	NRI		IDI	
	NRI[95%CI]	*P*-value	IDI[95%CI]	*P*-value
Subgroup1:BMI<25kg/m^2				
Model1	0.5127[0.2489-0.7765]	<0.001	0.005[0.002-0.008]	<0.05
Model2	-0.0573[-0.3293-0.2147]	0.67969	-0.0019[-0.0072-0.0035]	0.49897
Model3	0.02[-0.252-0.2921]	0.88526	-0.0022[-0.0171-0.0126]	0.76738
Model4	-0.4112[-0.6818--0.1406]	<0.05	-0.0072[-0.0228-0.0083]	0.36256
Subgroup2:BMI⩾25kg/m^2				
Model1	0.3795[0.2432-0.5157]	<0.001	0.008[0.0046-0.0113]	<0.001
Model2	0.4211[0.2849-0.5573]	<0.001	0.0126[0.0071-0.0181]	<0.001
Model3	0.2853[0.1493-0.4214]	<0.001	0.0072[6*10^-4-0.0137]	<0.001
Model4	0.3089[0.1726-0.4451]	<0.001	0.0084[0.0017-0.0151]	<0.05

States. Extrapolating these results requires expanding the scope of this study to provide additional evidence.

Conclusion

The TyG and TyG-WC indices were associated with HF. When a patient's BMI was categorized as normal weight or underweight, the TyG index was associated with HF when combined with demographic characteristics and comorbidities. The TyG-WC index also demonstrated greater accuracy when combined with additional information. In overweight or obese patients, both indices were associated with HF. However, the TyG-WC index had low sensitivity when used alone, making it unsuitable for use in predicting HF. Clinicians can refer to these results to select indices to assess the risk of HF. The TyG index should not be used alone to assess a BMI of 25 kg/m^2 or less. Waist circumference should be considered also.

The relationship between metabolism and cardiovascular diseases has been widely discussed. Montaigne et al. [28] found that peroxisome proliferator-activated receptor-α (PPARα), PPARδ and PPARγ regulated lipoprotein metabolism, stimulated glucose utilization, stored triglycerides in lipid droplets, and increased insulin sensitivity. PPAR also resists the atherosclerotic and inflammatory processes. Therefore, fat metabolism plays an important role in HF. Wen et al. [29] found in a retrospective cohort study that a one-unit increase in the hepatic steatosis index increased the risk of major adverse cardiovascular events by 43%. Dalt et al. [30] found that, in patients with cardiomyopathy and heart failure, an imbalance between fatty acid intake and oxidation leads to changes in the main energy substrate, which is an important factor causing myocardial damage. The familiar and widely used drug semaglutide stimulates glycolysis and reduces mitochondrial damage, lipid accumulation, and energy deficiency, thereby improving heart function and reducing stress load in patients with HF [31].

In addition, researchers have broadened the scope of metabolic research in recent years. Attention to iron metabolism has gradually increased in recent years. Docherty et al. [32] analyzed 3009 patients and found that decreased transferrin saturation, ferritin level, increased total iron-binding capacity, and soluble transferrin receptors may influence the effect of dapagliflozin.

Future studies should focus on the effects of metabolism on HF. In-depth studies should focus on elucidating the mechanisms of metabolism in patients with HF and exploring accurate clinical prediction scores.

Author contributions
Wang C.Y., together with Wang J.X., Huang Y., and Zhang Y.H. proposed the research topic. Wang C.Y. and Wang J.X. designed the research program, implemented the research process, collected data, and performed the statistical analysis. All authors were responsible for drafting and revising the article based on the suggestions of Huang Y. and Zhang Y.H.Huang Y. and Zhang Y.H. reviewed the thesis, obtained research funding, and provided material support and academic guidance.

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Data availability
All the data were downloaded directly from the National Health and Nutrition Examination Survey (NHANES).

Declarations

Ethical approval
Not applicable.

Competing interests
The authors declare no competing interests.

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