

PREDICTIVE VALUE OF THE TRIGLYCERIDE-GLUCOSE INDEX COMBINED WITH NOVEL BODY SHAPE INDICES FOR CARDIOVASCULAR DISEASE: A CROSS-SECTIONAL STUDY BASED ON NHANES

Y. ZHENG¹, Q. LI^{2,3,4}

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¹Hebei North University, Hebei, China

²Beijing University of Chinese Medicine, Beijing, China

³Dongfang Hospital, Beijing, China

⁴Qinhuangdao Hospital of Traditional Chinese Medicine, Hebei, China

CORRESPONDING AUTHOR

Quan Li, MD; e-mail: liquanwwwjjjj@163.com

ABSTRACT – Objective: Cardiovascular disease (CVD) remains one of the leading causes of death worldwide. Insulin resistance (IR) and central obesity are key contributors. The triglyceride–glucose (TyG) index is a simple surrogate for IR, while novel adiposity indices, such as the visceral adiposity index (VAI), lipid accumulation product (LAP), cardiometabolic index (CMI), body roundness index (BRI), and a body shape index (ABSI), better reflect body fat distribution. However, the predictive value of combining TyG with these indices for CVD risk remains unclear.

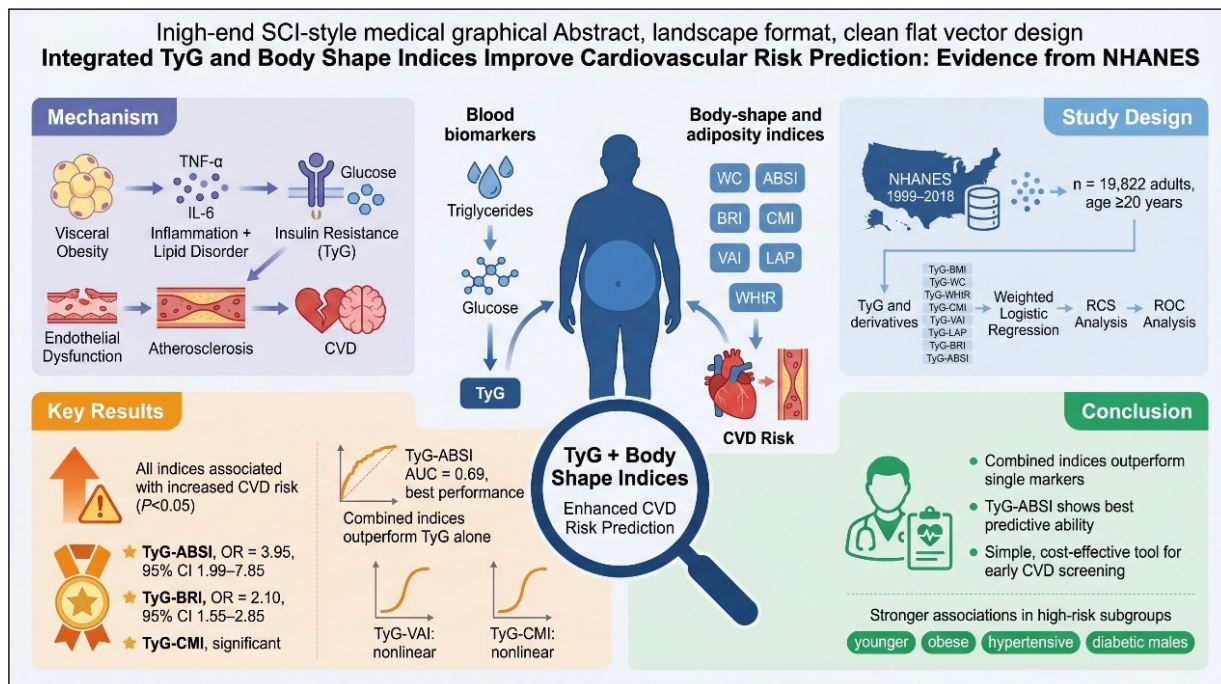
Materials and Methods: This cross-sectional study used data from 19,822 adults aged ≥20 years in the U.S. NHANES (1999–2018). CVD was defined by self-reported physician diagnosis. The TyG index and its derivatives (TyG-BMI, TyG-WC, TyG-WHtR, TyG-CMI, TyG-VAI, TyG-LAP, TyG-BRI, TyG-ABSI) were calculated. Weighted logistic regression and restricted cubic spline (RCS) analyses assessed associations and potential nonlinear relationships. Receiver operating characteristic (ROC) curves compared predictive performance.

Results: All TyG-derived indices were significantly associated with higher CVD risk ($p < 0.05$). The strongest associations were observed for TyG-ABSI (OR=3.95, 95% CI: 1.99–7.85) and TyG-BRI (OR=2.10, 95% CI: 1.55–2.85). TyG-VAI and TyG-CMI showed nonlinear relationships with CVD. In ROC analysis, TyG-ABSI achieved the highest discriminative power (AUC=0.69), outperforming TyG and other indices. Subgroup analyses revealed stronger associations among younger, obese, hypertensive, and diabetic males.

Conclusions: Combining the TyG index with body-shape indices markedly improved CVD risk prediction. TyG-ABSI, TyG-BRI, and TyG-CMI showed superior diagnostic performance and may serve as cost-effective tools for early CVD risk assessment in clinical and public health settings.

KEYWORDS: Triglyceride–glucose index, Novel body-shape indices, NHANES, Cardiovascular disease, Insulin resistance, Obesity.

LIST OF ABBREVIATIONS: CVD: Cardiovascular disease, TyG: Triglyceride-glucose, NHANES: National Health and Nutrition Examination Survey, TyG-WC: Glucose triglyceride-waist circumference, TyG-WHtR: Glucose triglyceride-waist height ratio, TyG-BMI: Glucose triglyceride-body mass index, TyG-CMI: Glucose triglyceride- cardiometabolic index TyG-VAI: Glucose triglyceride- visceral adiposity index, TyG-LAP: Glucose triglyceride- lipid accumulation product, TyG-BRI: Glucose triglyceride-body roundness index, TyG-ABSI: Glucose triglyceride- a body shape index, IR: Insulin resistance, WC: waist circumference, WHtR: waist height ratio, BMI: body mass index VAI: visceral adiposity index, LAP: lipid accumulation product, CMI: cardiometabolic index, BRI: body roundness index, ABSI: a body shape index, RCS: Restricted cubic spline, ROC: Receiver operating characteristic triglycerides, TG: triglycerides, HDL-C: high-density lipoprotein cholesterol, ORs: Odds ratios, CI: Confidence intervals.



Graphical Abstract. This cross-sectional study evaluated the association and predictive performance of the triglyceride-glucose (TyG) index combined with novel body-shape indices for cardiovascular disease (CVD) in 19,822 adults from the U.S. National Health and Nutrition Examination Survey (NHANES) 1999–2018. Weighted logistic regression, restricted cubic spline, and receiver operating characteristic analyses were performed. All TyG-derived indices were significantly associated with CVD risk. Among the evaluated indices, TyG-ABSI showed the highest discriminative performance (AUC = 0.69), while TyG-BRI and TyG-CMI also demonstrated strong associations with CVD. These findings suggest that combining the TyG index with novel body-shape indices may provide simple and cost-effective tools for CVD risk assessment.

INTRODUCTION

Cardiovascular diseases (CVDs) remain a leading cause of global mortality¹ and represent a major and ongoing challenge to public health, contributing substantially to the global disease burden. The persistent increase in CVD mortality over recent years suggests a worsening burden of population-level risk factors^{2,3}. The elevated health-care expenditures and associated psychological distress considerably impair patients' quality of life. The persistent increase in CVD mortality over recent years³ suggests a worsening burden of population-level risk factors. Therefore, creating and optimizing widely applicable, cost-effective risk prediction tools is essential for enhancing the prevention and management of CVD.

Insulin resistance (IR) represents a key pathophysiological mechanism underlying the development and progression of CVD. The triglyceride-glucose (TyG) index, calculated from fasting triglyceride and fasting blood glucose levels, has emerged as a reliable surrogate marker of IR. It demonstrates high sensitivity and specificity and is more accessible and cost-effective than direct insulin measurements. Previous studies^{4–6} have linked the TyG index to a range of adverse cardiovascular outcomes, including heart failure and

acute coronary syndrome, underscoring its potential value in CVD risk stratification.

Concurrently, the global obesity epidemic remains a pressing public health issue, with various obesity-related phenotypes and patterns of body fat distribution independently contributing to CVD risk⁷. In addition to conventional anthropometric measures — such as body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR)⁸ — several novel body-shape indices have been proposed. These include the cardiometabolic index (CMI), visceral adiposity index (VAI), lipid accumulation product (LAP), a body shape index (ABSI), and body roundness index (BRI). Such indices offer improved sensitivity in assessing visceral adiposity, dysregulated lipid metabolism, and specific body shape phenotypes. A growing body of evidence links these metrics to both the incidence of CVD and all-cause mortality^{9–12}.

Nevertheless, large-scale nationally representative studies in the U.S. general population comprehensively evaluating the predictive value of combining the TyG index with these novel adiposity indices for prevalent CVD and directly comparing their performance with that of the TyG index combined with conventional obesity measures remain limited. Given that the TyG index reflects systemic insulin sensitivity and met-

abolic homeostasis, while the novel indices more accurately capture visceral fat distribution and metabolic burden, integrating these indices may provide complementary prognostic information. To address this gap, this study employs cross-sectional data from the National Health and Nutrition Examination Survey (NHANES) to: (1) examine the association between the TyG index combined with novel body-shape indices and prevalent CVD; (2) compare the predictive performance of these combined models against those incorporating the TyG index and traditional measures (BMI, WC, WHtR); and (3) perform subgroup and dose-response analyses where applicable. This research aims to support the use of these readily available and economical composite markers — integrating metabolic and morphological phenotypes — for improved CVD risk stratification.

MATERIALS AND METHODS

Data source and study population

The National Health and Nutrition Examination Survey (NHANES), conducted by the Centers for Disease Control and Prevention, employs a complex, multistage, probability sampling design to

obtain a nationally representative sample of the non-institutionalized U.S. population. The survey collects comprehensive data, including demographic, dietary, examination, laboratory, and questionnaire information. The NHANES study protocols were approved by the National Center for Health Statistics (NCHS) Ethics Review Board. The protocols for NHANES 1999-2004, 2005-2010, 2011-2016, and 2017-2018 were approved under Protocol #98-12, Protocol #2005-06 (including its continuation), Protocol #2011-17 (including its continuation), and Protocol #2018-01, respectively. Written informed consent was obtained from all participants.

For this cross-sectional analysis, data from 101,316 adult participants across NHANES cycles from 1999 to 2018 were initially considered. The study was restricted to participants aged ≥ 20 years. To ensure analytical validity and proper application of complex survey weights, we excluded individuals with missing data on: (1) cardiovascular disease (CVD) status; (2) core anthropometric and metabolic parameters necessary to calculate the obesity and metabolic indices (including BMI, WC, WHtR, TyG, CMI, VAI, LAP, ABSI, and BRI); or (3) any of the predefined covariates. After these exclusions, the final analytical sample included 19,822 participants (Figure 1).

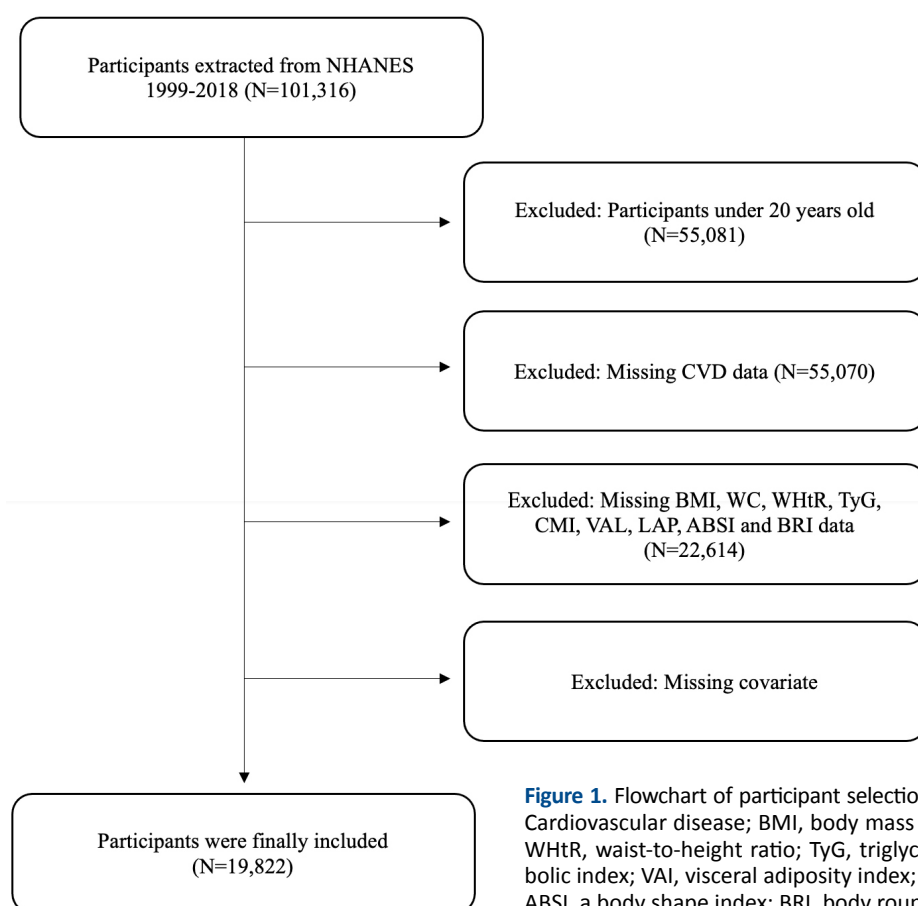


Figure 1. Flowchart of participant selection from NHANES 1999-2018. CVD, Cardiovascular disease; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; CMI, cardiometabolic index; VAI, visceral adiposity index; LAP, lipid accumulation product; ABSI, a body shape index; BRI, body roundness index.

Definition of TyG and novel body indices

The TyG index was employed as a surrogate measure of insulin resistance. Five novel body-shape indices were evaluated: VAI, LAP, CMI, ABSI, and BRI¹³⁻¹⁶. VAI, a marker of visceral fat accumulation, was calculated based on anthropometric measures [BMI and waist circumference (WC)] and lipid profiles [triglycerides (TG) and high-density lipoprotein cholesterol (HDL-C)]. LAP, reflecting central lipid storage, was derived from WC and TG. CMI integrates both adiposity and dyslipidemia components. ABSI, proposed by Krakauer and Krakauer¹⁷, reflects abdominal adiposity. BRI, incorporating WC and height, estimates whole-body adiposity. In addition, traditional anthropometric measures were included: BMI was computed as weight (kg) divided by height squared (m²), and waist-to-height ratio (WHtR) as WC (cm) divided by height (cm). Composite indices were generated by multiplying the TyG index by each obesity-related index (e.g., TyG-BMI, TyG-WC, TyG-WHtR, TyG-CMI, TyG-VAI, TyG-LAP, TyG-BRI, TyG-ABSI) (Table I). Participants were categorized into quartiles (Q1–Q4) for each combined metric, with Q1 designated as the reference category.

Outcome variable

Prevalent CVD was determined based on self-reported data collected through a standardized medical conditions questionnaire. Participants were specifically asked, “Has a doctor or other health professional ever told you that you had

congestive heart failure, coronary heart disease, angina, myocardial infarction, or stroke?”. Those who responded affirmatively to any of these conditions were classified as having CVD.

Assessment of covariates

Based on established risk factors from previous literature¹⁸, we selected the following covariates, which were obtained from NHANES interview questionnaires and physical examination data:

- Demographic and socioeconomic factors: age, gender (male, female).
- Ethnicity (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Other Ethnicity).
- Education attainment (less than 9th grade, 9–11th grade, high school grad/GED, some college or AA degree, college graduate or above).
- Marital status (married/cohabiting, never married, widowed/divorced/separated).
- Family poverty-income ratio (PIR) categorized as low (<1.39), medium (1.39–3.49), or high (≥3.49).
- Smoking status was defined as having smoked at least 100 cigarettes in a lifetime.
- Body Mass Index (BMI) was categorized as normal weight (<25 kg/m²), overweight (25–29.9 kg/m²), or obese (≥30 kg/m²).
- Hypertension was defined as a self-reported physician diagnosis, current use of antihypertensive medication, or an average systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg¹⁹.

Table I. Calculation formulas.

Index	Formula
TyG	$\ln [\text{Fasting TG (mg/dL)} \times \text{Fasting Glucose (mg/dL)} / 2]$
TyG-BMI	$\text{TyG} \times \text{BMI}$, $\text{BMI} = \text{weight (kg)} / \text{height (cm)}^2$
TyG-WC	$\text{TyG} \times \text{WC (cm)}$
TyG-WHtR	$\text{TyG} \times \text{WHtR}$, $\text{WHtR} = \text{WC (cm)} / \text{height (cm)}$
TyG-CMI	$\text{TyG} \times \text{CMI}$, $\text{CMI}^{13} = \text{WtHR} \times \text{TG (mmol L}^{-1}) / \text{HDL-C (mmol L}^{-1})$
TyG-VAI	$\text{TyG} \times \text{VAI}_{\text{male}}^{14} = \left[\frac{\text{WC}}{39.68 + (1.88 \times \text{BMI})} \times (\text{TG} / 1.03) \times (1.31 / \text{HDL}) \right]$
	$\text{TyG} \times \text{VAI}_{\text{female}}^{14} = \left[\frac{\text{WC}}{36.58 + (1.89 \times \text{BMI})} \times (\text{TG} / 0.81) \times (1.52 / \text{HDL}) \right]$
TyG-LAP	$\text{TyG} \times \text{LAP}_{\text{male}}^{15}$, $\text{LAP}_{\text{male}}^{15} = (\text{WC} - 65) \times \text{TG}$
	$\text{TyG} \times \text{LAP}_{\text{female}}^{15}$, $\text{LAP}_{\text{female}}^{15} = (\text{WC} - 58) \times \text{TG}$
TyG-BRI	$\text{TyG} \times \text{BRI}$, $\text{BRI}^{16} = 364.2 - 365.5 \times \sqrt{1 - \frac{(\text{WC} / (2\pi))^2}{(0.5 \times \text{height})^2}}$
TyG-ABSI	$\text{TyG} \times \text{ABSI}$, $\text{ABSI}^{17} = \frac{\text{WC}}{\text{BMI}^2 \times \text{height}^{1/2}}$

TyG, triglyceride-glucose; CVD, Cardiovascular disease; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; CMI, cardiometabolic index; VAI, visceral adiposity index; LAP, lipid accumulation product; ABSI, a body shape index; BRI, body roundness index.

- Diabetes was defined as a self-reported physician diagnosis, current use of glucose-lowering medication, a fasting plasma glucose level ≥ 7.0 mmol/L, a hemoglobin A1c level $\geq 6.5\%$, or a 2-hour oral glucose tolerance test result ≥ 11.1 mmol/L²⁰.

Statistical analysis

All statistical analyses were performed using R software (version 4.5.1, Vienna, Austria). Continuous variables are summarized as mean $\pm$ standard deviation (SD), and categorical variables as frequencies with percentages. Intergroup differences for continuous and categorical variables were evaluated using *t*-tests and chi-square tests, respectively. Weighted logistic regression was employed to assess the associations between the TyG index and its derived indices (modeled as continuous variables) and the prevalence of CVD. To improve comparability across indices and avoid inflated effect estimates caused by differences in measurement scales, all continuous TyG-derived indices were standardized before regression analyses. Therefore, odds ratios for continuous variables are reported per 1-SD increase. Quartile-based analyses were additionally performed using Q1 as the reference category. These indices were also analyzed in quartile form to examine potential dose-response relationships. The results are reported as odds ratios (OR) with 95% confidence intervals (CI). Four progressively adjusted models were constructed to adjust for potential confounders: Model 0: crude model. Model 1: Adjusted for age, sex, and ethnicity. Model 2: Additionally adjusted for poverty-income ratio, BMI, education level, smoking status, and marital status. Model 3: Further adjusted for history of hypertension and diabetes. Non-linear relationships between the indices and CVD were explored using restricted cubic spline analysis, with knots placed at the 5th, 35th, 65th, and 95th percentiles of each index to minimize the influence of extreme values. The discriminative ability of each index for CVD was evaluated *via* receiver operating characteristic (ROC) curve analysis, and the area under the curve (AUC) along with its 95% CI was computed. Finally, subgroup analyses were conducted to assess the consistency of the associations across pre-specified clinical strata: sex (male/female), age ($<60/\geq 60$ years), BMI ($\geq 25/<25$ kg/m²), and the presence or absence of hypertension, smoking history, and diabetes. The potential for effect modification was formally tested by including interaction terms in the regression models. A two-tailed $p < 0.05$ was considered statistically significant.

RESULTS

Basic characteristics of participants

This study included a total of 19,822 participants from 1999-2018. The baseline characteristics of the participants, stratified by CVD status, are presented in Table II. Among the total cohort, 2,168 (8.9%) participants had established CVD, while 17,654 (89.1%) were free from CVD. Participants with CVD were significantly older than those without (mean age 64 ± 13 years vs. 46 ± 16 years). CVD was more prevalent among males ($n=1,248$) than females ($n=920$). Most participants were non-Hispanic White ($n=9,142$), who also constituted the largest proportion of CVD cases ($n=1,231$). Comparisons between the CVD and non-CVD groups revealed statistically significant differences ($p < 0.05$) across all examined variables. These included socioeconomic factors (poverty-income ratio, education attainment), clinical comorbidities (hypertension, diabetes), behavioral factors (smoking status), and all TyG-related indices (TyG, TyG-BMI, TyG-WC, TyG-WHtR, TyG-CMI, TyG-VAI, TyG-LAP, TyG-BRI, TyG-ABSI). Specifically, compared to participants without CVD, those with CVD were more likely to be older, male, non-Hispanic White, and have a lower income, a higher BMI, a history of smoking, a lower education level, a marital status of widowed/divorced/separated, and comorbidities including hypertension and diabetes. Furthermore, all TyG and combined TyG-obesity indices were significantly elevated in the CVD group.

Association analysis

The results of the logistic regression analysis examining the association between TyG, its combined indices, and CVD are presented in Table III. In the fully adjusted Model 3, when analyzed as continuous indices, TyG-BMI, TyG-WC, TyG-WHtR, TyG-CMI, TyG-VAI, TyG-LAP, TyG-BRI, and TyG-ABSI, each standard deviation increase in TyG-CMI, TyG-VAI, TyG-BRI, and TyG-ABSI was associated with higher odds of CVD, 1.00, 1.00, 1.27, 1.08, 1.00, 2.10, and 3.95, respectively. The standalone TyG index was significantly associated with CVD in Model 2 (OR=1.29, 95% CI: 1.14-1.45). When analyzed by quartiles, participants in the highest quartile (Q4) of TyG-WC, TyG-WHtR, TyG-CMI, TyG-VAI, TyG-LAP, TyG-BRI, and TyG-ABSI exhibited significantly increased CVD risks compared to those in the lowest quartile (Q1), with corresponding ORs of 1.59 (95% CI: 1.12, 2.26), 1.53 (1.09, 2.13), 1.86 (1.44, 2.42), 1.36 (1.07, 1.72), 1.34 (1.03, 1.75), 1.66 (1.12, 2.46), and 1.36 (1.04, 1.78).

Table II. Weighted baseline characteristics of participants.

Characteristic	Overall, N = 19,822 (100%) ¹	No, N = 17,654 (91.2%) ¹	Yes, N = 2,168 (8.8%) ¹	p ²
Age (years)	47 (17)	46 (16)	64 (13)	<0.001
Sex				<0.001
Female	9,909 (51%)	8,989 (51%)	920 (45%)	
Male	9,913 (49%)	8,665 (49%)	1,248 (55%)	
Ethnicity				<0.001
Non-Hispanic White	9,142 (70%)	7,911 (69%)	1,231 (75.4%)	
Non-Hispanic Black	3,888 (10%)	3,455 (10.1%)	433 (10.4%)	
Mexican American	3,401 (8.0%)	3,160 (8.5%)	241 (4.1%)	
Other Ethnicity	1,805 (7.0%)	1,684 (7.2%)	121 (6.7%)	
Other Hispanic	1,586 (5.0%)	1,444 (5.2%)	142 (3.4%)	
PIR				<0.001
High (>3.49)	6,228 (43%)	5,728 (44%)	500 (31%)	
Low (≤1.39)	6,494 (22%)	5,652 (22%)	842 (28%)	
Medium (>1.39, ≤3.49)	7,100 (35%)	6,274 (34%)	826 (41%)	
BMI				<0.001
Normal (<25)	5,943 (31%)	5,450 (32%)	493 (22%)	
Obese (≥30)	7,124 (36%)	6,185 (35%)	939 (46%)	
Overweight (≥25, <30)	6,755 (33%)	6,019 (33%)	736 (32%)	
Smoking status				<0.001
No-smoker	10,560 (54%)	9,728 (55%)	832 (37%)	
Smoker	9,262 (46%)	7,926 (45%)	1,336 (63%)	
Education attainment				<0.001
Less than 9 th grade	2,249 (6.0%)	1,893 (5.2%)	356 (9.4%)	
9-11 th grade	2,900 (11%)	2,495 (10.4%)	405 (16.3%)	
High school grad/GED	4,568 (23%)	4,042 (23.4%)	526 (26.3%)	
Some college or AA degree	5,685 (31%)	5,139 (31%)	546 (28%)	
College graduate or above	4,420 (29%)	4,085 (30%)	335 (20%)	
Marital status				<0.001
Married/cohabiting	12,161 (65%)	10,887 (65%)	1,274 (64.3%)	
Never married	3,323 (17%)	3,203 (18%)	120 (4.3%)	
Widowed/divorced/separated	4,338 (18%)	3,564 (17%)	774 (31.4%)	
Hypertension	8,410 (38%)	6,745 (34%)	1,665 (75%)	<0.001
Diabetes	3,788 (15%)	2,876 (13%)	912 (39%)	<0.001
TyG	8.61 (0.67)	8.59 (0.66)	8.86 (0.70)	<0.001
TyG-BMI	250 (67)	248 (66)	269 (70)	<0.001
TyG-WC	858 (179)	850 (176)	943 (182)	<0.001
TyG-WHtR	5.08 (1.05)	5.03 (1.03)	5.62 (1.06)	<0.001
TyG-CMI	1.57 (1.42)	1.52 (1.38)	2.08 (1.62)	<0.001
TyG-VAI	19 (30)	19 (28)	24 (47)	<0.001
TyG-LAP	540 (696)	523 (684)	710 (790)	<0.001
TyG-BRI	3.73 (0.45)	3.71 (0.45)	3.96 (0.40)	<0.001
TyG-ABSI	-0.36 (0.11)	-0.37 (0.11)	-0.29 (0.10)	<0.001

¹Mean ± SD for continuous; n (%) for categorical.²Design-based t-test; Pearson's χ^2 : Rao & Scott adjustment.

CVD, Cardiovascular disease; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; CMI, cardiometabolic index; VAI, visceral adiposity index; LAP, lipid accumulation product; ABSI, a body shape index; BRI, body roundness index; PIR, poverty-income ratio.

Table III. Associations between standardized TyG-derived indices and CVD.

	Model 0 OR (95% CI)	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
TyG (Continuous)	1.47 (1.37, 1.56)***	1.32 (1.22, 1.42)***	1.19 (1.09, 1.29)***	1.04 (0.97, 1.13)
TyG (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	1.53 (1.23, 1.91)***	1.08 (0.85, 1.37)	0.97 (0.76, 1.23)	0.91 (0.71, 1.17)
Q3	2.10 (1.72, 2.57)***	1.33 (1.06, 1.67)*	1.10 (0.87, 1.38)	0.96 (0.76, 1.21)
Q4	3.00 (2.43, 3.71)***	1.83 (1.47, 2.28)***	1.37 (1.09, 1.72)**	1.03 (0.82, 1.29)
TyG-BMI (Continuous)	1.32 (1.24, 1.41)***	1.39 (1.29, 1.50)***	1.38 (1.25, 1.52)***	1.18 (1.06, 1.31)**
TyG-BMI (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	1.58 (1.28, 1.94)***	1.06 (0.85, 1.32)	1.01 (0.76, 1.35)	0.89 (0.67, 1.19)
Q3	1.73 (1.39, 2.15)***	1.24 (0.99, 1.54)	1.01 (0.70, 1.46)	0.79 (0.54, 1.15)
Q4	2.42 (1.94, 3.02)***	2.06 (1.64, 2.59)***	1.47 (0.97, 2.22)	0.90 (0.59, 1.37)
TyG-WC (Continuous)	1.60 (1.50, 1.70)***	1.49 (1.38, 1.61)***	1.49 (1.35, 1.64)***	1.26 (1.14, 1.39)***
TyG-WC (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	1.99 (1.51, 2.63)***	1.21 (0.91, 1.61)	1.25 (0.92, 1.70)	1.14 (0.83, 1.56)
Q3	2.68 (2.10, 3.41)***	1.46 (1.13, 1.88)**	1.45 (1.07, 1.96)**	1.20 (0.88, 1.65)
Q4	4.40 (3.38, 5.73)***	2.56 (1.95, 3.35)***	2.31 (1.63, 3.26)***	1.59 (1.12, 2.26)*
TyG-WHtR (Continuous)	1.67 (1.57, 1.78)***	1.51 (1.40, 1.63)***	1.51 (1.37, 1.67)***	1.28 (1.15, 1.41)***
TyG-WHtR (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	2.34 (1.81, 3.02)***	1.33 (1.00, 1.76)	1.39 (1.02, 1.90)*	1.23 (0.90, 1.69)
Q3	3.03 (2.40, 3.83)***	1.52 (1.18, 1.95)**	1.52 (1.12, 2.06)**	1.23 (0.91, 1.68)
Q4	5.24 (4.10, 6.69)***	2.66 (2.05, 3.43)***	2.35 (1.68, 3.28)***	1.53 (1.09, 2.13)**
TyG-CMI (Continuous)	1.31 (1.23, 1.39)***	1.29 (1.21, 1.37)***	1.20 (1.14, 1.27)***	1.12 (1.06, 1.18)***
TyG-CMI (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	1.94 (1.49, 2.51)***	1.55 (1.18, 2.03)**	1.41 (1.06, 1.86)**	1.31 (0.99, 1.73)
Q3	2.54 (2.02, 3.20)***	1.85 (1.46, 2.36)***	1.54 (1.20, 1.98)***	1.38 (1.07, 1.77)**
Q4	4.28 (3.38, 5.43)***	3.07 (2.41, 3.90)***	2.36 (1.82, 3.07)***	1.86 (1.44, 2.42)***
TyG-VAI (Continuous)	1.14 (1.08, 1.20)***	1.17 (1.11, 1.24)***	1.11 (1.06, 1.15)***	1.06 (1.03, 1.11)**
TyG-VAI (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	1.47 (1.17, 1.84)***	1.34 (1.06, 1.70)**	1.21 (0.94, 1.55)	1.15 (0.89, 1.49)
Q3	1.85 (1.50, 2.29)***	1.58 (1.26, 1.97)***	1.26 (1.00, 1.59)*	1.14 (0.91, 1.44)
Q4	2.47 (1.98, 3.07)***	2.19 (1.75, 2.73)***	1.63 (1.29, 2.07)***	1.36 (1.07, 1.72)**
TyG-LAP (Continuous)	1.21 (1.13, 1.30)***	1.20 (1.11, 1.30)***	1.10 (1.04, 1.16)***	1.05 (1.00, 1.10)
TyG-LAP (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	2.02 (1.63, 2.50)***	1.31 (1.05, 1.64)**	1.22 (0.97, 1.54)	1.15 (0.90, 1.46)
Q3	2.20 (1.80, 2.71)***	1.31 (1.05, 1.63)**	1.07 (0.84, 1.37)	0.96 (0.74, 1.23)
Q4	3.64 (2.89, 4.60)***	2.37 (1.86, 3.00)***	1.70 (1.30, 2.23)***	1.34 (1.03, 1.75)*
TyG-BRI (Continuous)	1.55 (1.47, 1.64)***	1.45 (1.36, 1.56)***	1.46 (1.33, 1.59)***	1.28 (1.16, 1.41)***
TyG-BRI (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	2.21 (1.72, 2.85)***	1.26 (0.96, 1.66)	1.37 (1.01, 1.86)*	1.22 (0.90, 1.66)
Q3	3.05 (2.40, 3.87)***	1.53 (1.20, 1.96)***	1.67 (1.20, 2.32)**	1.34 (0.96, 1.88)
Q4	4.97 (3.86, 6.40)***	2.54 (1.97, 3.27)***	2.46 (1.69, 3.58)***	1.66 (1.12, 2.46)**
TyG-ABSI (Continuous)	2.03 (1.90, 2.17)***	1.47 (1.37, 1.59)***	1.31 (1.21, 1.42)***	1.16 (1.08, 1.24)***
TyG-ABSI (Category)				
Q1	Reference	Reference	Reference	Reference
Q2	2.22 (1.71, 2.88)***	1.31 (0.98, 1.74)	1.15 (0.86, 1.54)	1.09 (0.82, 1.46)
Q3	3.85 (2.97, 4.99)***	1.61 (1.21, 2.13)**	1.30 (0.98, 1.73)	1.15 (0.87, 1.53)
Q4	7.70 (6.07, 9.78)***	2.49 (1.90, 3.26)***	1.78 (1.34, 2.35)*	1.36 (1.04, 1.78)*

For continuous analyses, all TyG-derived indices were standardized, and ORs are reported per 1-SD increase. Quartile analyses used Q1 as the reference group. Model 0: Unadjusted; Model 1: Adjusted for age, sex, ethnicity; Model 2: Adjusted for age, sex, ethnicity, PIR, BMI, education, smoking, marital status; Model 3: Additionally adjusted for hypertension and diabetes history. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Restricted cubic spline (RCS) analysis

We employed restricted cubic spline analysis within a robustly adjusted model to investigate the potential shape of the associations between the TyG-derived indices and CVD risk. Significant nonlinear associations were observed for TyG-VAI and TyG-CMI (p for nonlinearity <0.05). In contrast, TyG, TyG-BMI, TyG-WC, TyG-WHtR, TyG-LAP, TyG-BRI, and TyG-ABSI showed an approximately linear association with CVD risk (p for nonlinearity >0.05) (Figure 2).

Receiver operating characteristic (ROC) analysis

To evaluate and compare the predictive performance of the TyG index combined with both novel and traditional body-shape indices, receiver operating characteristic (ROC) curves were generated across four progressively adjusted models. In the unadjusted model (Model 0), the area under the curve (AUC) values, in descending order, were:

TyG-ABSI (AUC=0.690), TyG-WHtR (AUC=0.647), TyG-BRI (AUC=0.644), TyG-WC (AUC=0.642), TyG-CMI (AUC=0.636), TyG-LAP (AUC=0.613), TyG (AUC=0.608), TyG-BMI (AUC=0.583), and TyG-VAI (AUC=0.583). These findings identified TyG-ABSI as the best-performing indicator in the unadjusted analysis. After multivariable adjustment, all composite indices exhibited high discriminatory ability, with AUC values exceeding 0.8, indicating their potential clinical utility in CVD risk stratification (Figure 3).

Subgroup analysis and interaction

Subgroup analyses revealed generally consistent positive associations between TyG-derived indices and CVD risk across all predefined strata (all p for interaction >0.05 ; [Supplementary Tables I–VIII](#)). Notably, TyG-ABSI — identified as the strongest predictor in our previous analyses — maintained a robust and significantly positive association with CVD risk regardless of gender, age, or comorbidity status (Table IV).

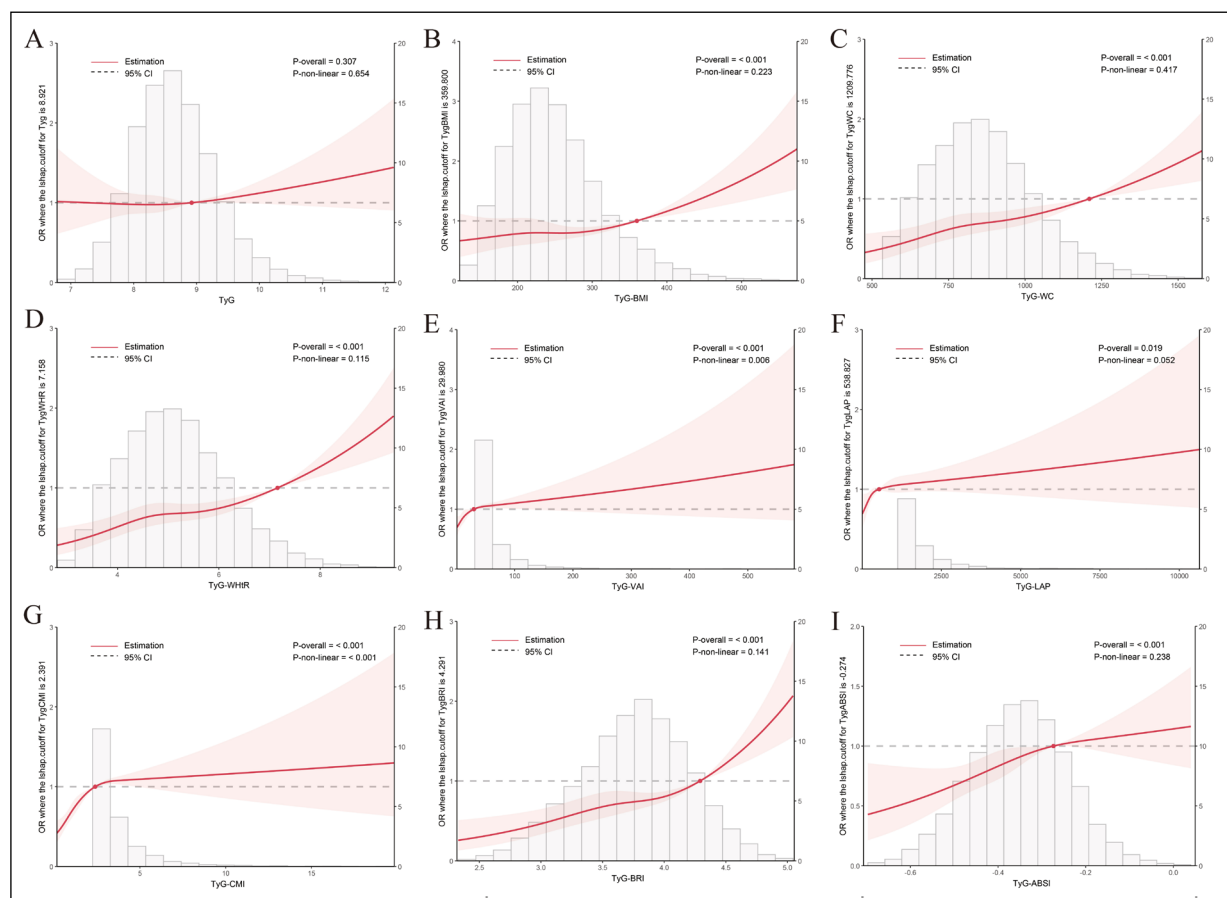


Figure 2. RCS analysis of the associations between TyG and its derived indices and CVD.

A, TyG; **(B)** TyG-BMI; **(C)** TyG-WC; **(D)** TyG-WHtR; **(E)** TyG-VAI; **(F)** TyG-LAP; **(G)** TyG-CMI; **(H)** TyG-BRI; **(I)** TyG-ABSI.

CVD, Cardiovascular disease; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; CMI, cardiometabolic index; VAI, visceral adiposity index; LAP, lipid accumulation product; ABSI, a body shape index; BRI, body roundness index.

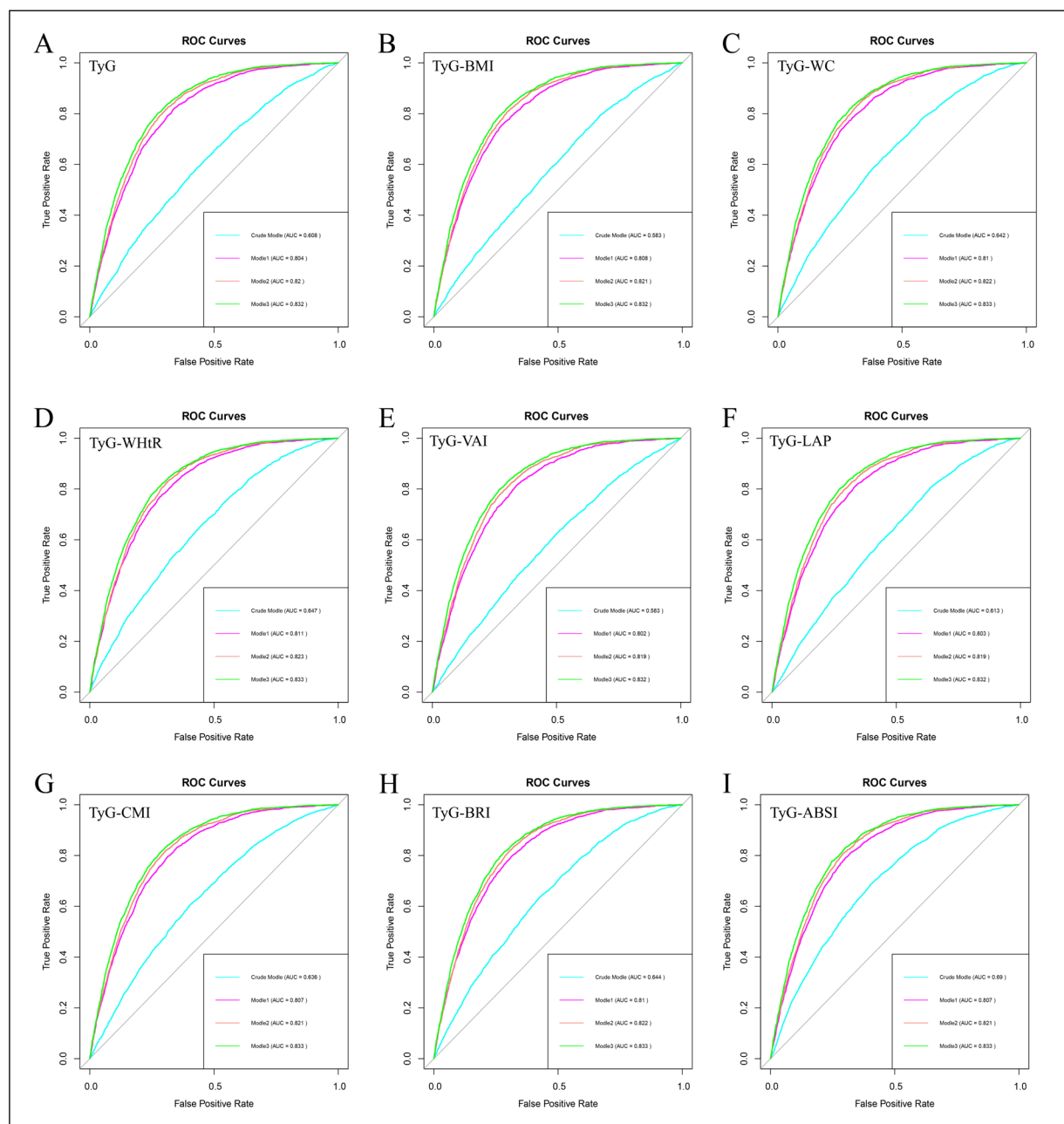


Figure 3. ROC analysis of the associations between TyG and its derived indices and CVD. **A,** TyG; **(B)** TyG-BMI; **(C)** TyG-WC; **(D)** TyG-WHtR; **(E)** TyG-VAI; **(F)** TyG-LAP; **(G)** TyG-CMI; **(H)** TyG-BRI; **(I)** TyG-ABSI.

CVD, Cardiovascular disease; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; CMI, cardiometabolic index; VAI, visceral adiposity index; LAP, lipid accumulation product; ABSI, a body shape index; BRI, body roundness index.

Model 0: Unadjusted; Model 1: Adjusted for age, sex, ethnicity; Model 2: Adjusted for age, sex, ethnicity, PIR, BMI, education, smoking, marital status; Model 3: Additionally adjusted for hypertension and diabetes history. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The effect size of TyG-ABSI was the highest among males, individuals aged <60 years, obese individuals, and those with hypertension or diabetes, suggesting stronger risk identification capability in populations with a heavier metabolic

abnormal burden. In contrast, TyG-BRI, TyG-CMI, TyG-VAI, TyG-BRI, TyG-CMI, and TyG-VAI also showed positive associations, though with relatively weaker effect magnitudes (Supplementary Tables VI-VIII).

Table IV. Subgroup analysis of the association between TyG-ABSI and CVD.

TyG-ABSI	OR (95% CI)	p-value	p for interaction
Age			0.03
<60	1.33 (1.18, 1.49)	<0.001	
≥60	1.15 (1.04, 1.28)	0.006	
Gender			0.262
Female	1.13 (1.01, 1.27)	0.036	
Male	1.19 (1.05, 1.35)	0.007	
Smoking status			0.618
No-smoker	1.16 (1.03, 1.32)	0.019	
Smoker	1.14 (1.03, 1.27)	0.011	
BMI			0.652
<25	1.14 (0.95, 1.36)	0.164	
≥25	1.17 (1.07, 1.28)	<0.001	
Diabetes			0.457
No	1.17 (1.06, 1.29)	0.002	
Yes	1.12 (1.00, 1.26)	0.046	
Hypertension			0.134
No	1.12 (0.96, 1.32)	0.157	
Yes	1.16 (1.06, 1.26)	0.001	

Adjusted for all covariates except effect modifier.

ABSI, a body shape index. TyG-ABSI was standardized, and ORs are reported per 1-SD increase.

DISCUSSION

This study used nationally representative data from NHANES to systematically evaluate the associations of the TyG index — both alone and in combination with traditional and novel body-shape indices — with cardiovascular disease risk. Our results indicate that all TyG-derived indices, including those based on traditional (BMI, WC, WHtR) and novel (CMI, VAI, LAP, BRI, ABSI) measures, were independently associated with increased CVD risk ($p < 0.05$). In continuous analysis, all derived indices (TyG-BMI, TyG-WC, TyG-WHtR, TyG-CMI, TyG-VAI, TyG-LAP, TyG-BRI, TyG-ABSI) were correlated with greater CVD prevalence. When analyzed by quartiles, most combined indices — except TyG-BMI — maintained a significant trend. RCS analyses identified nonlinear relationships for TyG-VAI and TyG-CMI, whereas most other indices exhibited approximately linear dose-response associations with CVD. In ROC analysis, TyG-ABSI showed the highest predictive performance in the unadjusted model (Model 0; AUC=0.69), outperforming the standalone TyG index (AUC=0.608) and other derivatives (AUC range: 0.58–0.65). In the fully adjusted model, all indices demonstrated high and comparable discriminatory capacity, with AUC values ranging from 0.83 to 0.84. Subgroup analyses revealed generally consistent associations across most populations, with TyG-ABSI exhibiting particularly strong associations in males under 60 years of age who had obesity, hypertension, and no diabetes.

The TyG index serves as a practical surrogate marker of insulin resistance and has been independently associated with multiple adverse cardiovascular outcomes, including coronary heart disease, heart failure, and stroke. This study demonstrated that integrating the TyG index with body-shape indices — particularly those reflecting fat distribution and metabolic dysregulation, such as TyG-ABSI, TyG-BRI, and TyG-CMI — demonstrated superior predictive performance compared with traditional combinations such as TyG-BMI and TyG-WC. Restricted cubic spline analyses revealed nonlinear associations for TyG-CMI and TyG-VAI, which may indicate compensatory or saturation effects between visceral adiposity and insulin resistance. These findings align with previously reported U-shaped risk curves in middle-aged, elderly, and obese populations^{21–23}.

The synergistic effect observed is likely attributable to the central adiposity phenotype captured by ABSI. Visceral adipose tissue acts as a metabolically active endocrine organ, releasing free fatty acids and pro-inflammatory cytokines — such as tumor necrosis factor (TNF)- α and interleukin (IL)-6 — while downregulating anti-inflammatory adiponectin. These alterations collectively exacerbate insulin resistance and promote chronic low-grade inflammation. Concurrently, the glucose-lipid metabolic imbalance reflected by the TyG index further aggravates oxidative stress and endothelial dysfunction. Collectively, these processes may form a self-reinforcing cycle

of “adiposity–inflammation–insulin resistance–endothelial injury,” which accelerates atherogenesis and helps explain the more pronounced association of TyG-ABSI in subgroups with obesity and hypertension^{24–26}.

Our subgroup analyses confirmed that the positive association between TyG-ABSI and CVD remained consistent across major demographic and clinical categories. Notably, TyG-ABSI exhibited larger effect sizes and higher AUC values among males, individuals under 60 years, and those with obesity, hypertension, or diabetes, indicating its enhanced utility for risk stratification in populations with elevated metabolic burden and central adiposity. These findings are supported by existing literature: TyG has been shown to robustly predict atherosclerosis, major adverse cardiovascular events, and mortality^{27,28}, while ABSI outperforms conventional measures such as BMI and WC in capturing central obesity and its associated CVD risks, including stroke and cardiovascular death^{29,30}. Moreover, prospective studies³¹ indicate that the combination of TyG and ABSI offers improved predictive performance for stroke compared to either indicator alone, reinforcing the complementary value of integrating metabolic and body shape phenotypes.

Our study possesses several notable strengths, including the use of a large, nationally representative sample derived from NHANES, which employed a complex sampling design to enhance the generalizability of our findings. We also applied a comprehensive analytical strategy — incorporating weighted logistic regression, restricted cubic spline analysis, ROC curve evaluation, and subgroup assessments — to rigorously examine the predictive utility of TyG-based indices. However, some limitations merit consideration. First, the use of self-reported data for certain variables may be susceptible to recall bias or misclassification. Second, several subgroup analyses were constrained by limited sample sizes, which may affect the stability and interpretability of the results. Finally, the cross-sectional nature of the data limits its causal inference; thus, future prospective or longitudinal studies are needed to validate these associations.

CONCLUSIONS

This study demonstrates that integrating the TyG index with novel body shape indices enables more effective identification of individuals at elevated CVD risk, outperforming single-indicator approaches. TyG-ABSI, TyG-BRI, and TyG-CMI exhibited the strongest discriminatory performance among the evaluated metrics. These findings suggest that sim-

ple composite measures combining TyG and body shape indices may serve as cost-effective and practical tools for CVD risk screening in both clinical and public health contexts. These findings may facilitate early identification of high-risk individuals and support preventive strategies targeting integrated metabolic-obesity phenotypes.

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DATA AVAILABILITY

The data in this article were obtained from publicly available sources.

ETHICS APPROVAL

This study utilized publicly available, de-identified data from the National Health and Nutrition Examination Survey (NHANES). The NHANES protocol was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board (ERB).

INFORMED CONSENT

All participants provided written informed consent.

AUTHORS' CONTRIBUTIONS

Z.Y. conceived the study, collected and analyzed the data, and drafted the manuscript. Z.Y. and L.Q. critically revised and approved the final manuscript. All authors have made significant contributions to the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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