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Association between triglyceride glucose-waist to height ratio (TyG-WHtR) and hypertension in adults aged 18–60: a cross-sectional study

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Abstract

Background This study aimed to explore the association between TyG and the prevalence of hypertension in US adults aged 18–60.

Method Data was obtained from the National Health and Nutrition Examination Survey (NHANES) covering the circles from 2009 to 2018, involving 12,309 adults aged 18 to 60. The biomarkers studied in this article included weight, body mass index (BMI), waist circumference (WC), weight-adjusted waist index (WWI), waist-to-height ratio (WHtR), triglyceride-glucose index (TyG), triglyceride glucose-body mass index (TyG-BMI), triglyceride glucose-waist circumference (TyG-WC), triglyceride glucose-weight (TyG-Weight), and triglyceride glucose-waist to height ratio (TyG-WHtR). Participants were categorized into a non-Hypertension group ($n=7,076$) and a Hypertension group ($n=5,233$). A weighted multiple logistic regression model was employed to evaluate the association between biomarkers and hypertension. Restricted cubic splines (RCS) were utilized to examine the non-linear association between biomarkers and the risk of developing hypertension. Threshold effect analysis was used to determine the inflection point. Receiver operating characteristic (ROC) curves were generated to assess the predictive performance of biomarkers for hypertension. Additionally, subgroup and interaction analyses were conducted to confirm the reliability of the associations observed.

Result Our analysis revealed that after adjusting for multiple variables, the risk of hypertension increased by 12% for each unit increase in TyG-WHtR ($P<0.001$). The RCS results showed a positive nonlinear association between TyG-WHtR and hypertension, with an inflection point of 5.79. Similar associations were also observed with WWI, WHtR, and TyG. The ROC curve analysis demonstrated that TyG-WHtR had the best predictive performance for hypertension

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(AUC: 0.6946, 95% CI: 0.6853–0.7039, Cut-off Value: 4.831, all P for comparison < 0.001). Subgroup analysis revealed that the association between TyG-WHtR and hypertension remains robust (all P for interaction > 0.05).

Conclusion There is a significant association between WWI, WHtR, TyG, and TyG-WHtR with hypertension in American adults aged 18 to 60, with TyG-WHtR demonstrating the best predicted performance.

Clinical trial number Not applicable.

Keywords Hypertension, NHANES, Triglyceride glucose index, TyG, TyG-WHtR

Background

According to the 2017 ACC/AHA clinical guidelines, individuals are classified as having hypertension if they have a systolic blood pressure (SBP) ≥ 130 mmHg, a diastolic blood pressure (DBP) ≥ 80 mmHg, or if they are already taking antihypertensive medication [1, 2]. As disclosed on the World Health Organization website [3], approximately 1.28 billion adults aged 30–79 worldwide are affected by hypertension, positioning it as a significant risk factor for cardiovascular diseases and other chronic conditions [4, 5]. Therefore, early detection and intervention for those at risk of hypertension are crucial in addressing the global impact of this health issue [6].

Numerous factors contribute to hypertension, including obesity, marital status, depression, physical activity, and salt intake [7–12]. Among these, age is a significant factor in the development of hypertension. The prevalence of hypertension varies notably across different age groups. In the United States, approximately 60.6% of individuals over 60 are affected, much higher than the rates observed in younger populations—14.5% in those aged 18–44 years and 40.3% in those aged 45–64 years [13]. Individuals aged 60 and above are defined as the elderly, and they are considered a special group in the assessment and treatment of hypertension [14]. Unlike hypertension in younger adults (aged < 60), elderly individuals often experience isolated systolic hypertension (ISH) [15]. This condition is characterized by high and fluctuating pulse pressure and is closely linked to peripheral vascular sclerosis [16]. Furthermore, elderly individuals often have conditions such as coronary heart disease (CHD) and diabetes, leading to a higher prevalence of secondary hypertension compared to younger people [17]. In contrast, hypertension in young adults is often associated with lifestyle factors, such as smoking, alcohol consumption, irregular sleeping patterns, and obesity [18]. Therefore, different hypertension management strategies should be adopted for different ages [19].

Identifying a biomarker that can predict the risk of hypertension is crucial for public health departments to make informed decisions about managing hypertension in populations. However, the effectiveness of various biomarkers in predicting hypertension differs based on factors such as age, region, and race, given the large global population and diverse geographical areas. For instance, among Caucasian men, body mass index (BMI) and waist circumference (WC) are more closely associated with the incidence of uncontrolled hypertension than they are in women [20]. In the adult population of China, WC is recognized as an independent risk factor for the development of new-onset hypertension cases [21]. Conversely, in Beijing, waist-to-height ratio (WHtR) is a better predictor of hypertension than BMI or WC [22]. A survey focusing on individuals aged 60 and above in the United States revealed a significant link between elevated weight-adjusted waist index (WWI) levels and the risk of hypertension [23]. Additionally, in the adult population of Algeria, the relationship between BMI, WC, and WHtR with hypertension appears to be less significant [24].

The triglyceride-glucose index (TyG index) and its derived parameters, such as the triglyceride glucose-body mass index (TyG-BMI), triglyceride glucose-waist circumference (TyG-WC), triglyceride glucose-weight (TyG-Weight), and triglyceride glucose-waist to height ratio (TyG-WHtR), are novel non-invasive biomarkers of insulin resistance (IR). An elevated TyG index signifies metabolic abnormalities [25]. Research has confirmed that TyG is associated with CVD [26–29]. The connection between TyG and hypertension has been well-established in Asia but remains scarce in other regions [30–33]. In the United States, hypertension has often been explored as a comorbidity alongside other diseases associated with TyG [34, 35]. However, there is currently a lack of research explicitly linking TyG to the risk of hypertension in American adults.

This study examined the association between the TyG index and hypertension in American adults aged 18 to 60, aiming to determine its effectiveness as a predictor of hypertension.

Method

Study populations

The National Health and Nutrition Examination Survey (NHANES) is a cross-sectional study to evaluate the health and nutritional status of adults and children in the United States. It is a key initiative of the National Center for Health Statistics (NCHS) and is part of the Centers for Disease Control and Prevention (CDC). The survey sample is carefully selected to represent the U.S. population

across all age groups and is conducted biennially. Each respondent provides data that includes demographic information, dietary habits, body measurements, examination results, laboratory findings, and questionnaire responses. Given the differences in age characteristics between elderly individuals and adults, our study focused on data from adults aged 18 to 60, utilizing information gathered from NHANES between 2009 and 2018. The NCHS Institutional Ethics Review Board approved the NHANES survey protocol, and this study did not involve any personally identifiable information, thus exempting it from further ethical review. All data used in this study are publicly available on the official NHANES website (https://wwwn.cdc.gov/nchs/nhanes/Default.aspx).

The survey initially included 49,693 individuals. Respondents younger than 18 or over 60 were excluded ($n = 22{,}464$), as were those without blood pressure and history of hypertension data ($n = 2$). Subsequently, Participants lack education, marriage, poverty-to-income ratio (PIR), personal habits (smoking, drinking), medical complications (such as congestive heart failure (CHF), CHD, diabetes, depression), physical activity (sedentary activity), physical measurement data (such as height, weight, BMI, WC), salt intakes (sodium and potassium), and serum biochemical data (such as glucose, triglyceride, potassium, sodium, creatinine) were excluded ($n = 8{,}918$). Ultimately, 12,309 participants were included in the study. These participants were divided into a non-Hypertension Group ($n = 7{,}076$) and a Hypertension group ($n = 5{,}233$). A detailed flow chart illustrating the participant selection process is shown in Fig. 1.

Independent variable

The biomarkers in this study served as independent variables and included the following: Weight, BMI, WC, WWI, WHtR, TyG, TyG-BMI, TyG-WC, TyG-Weight, and TyG-WHtR. The formulas for calculating these biomarkers are as follows:

$$\mathrm{WWI} = \frac{\mathrm{WC\,(cm)}}{\sqrt{\mathrm{weight\,(kg)}}}$$

$$\mathrm{WhtR} = \frac{\mathrm{WC\ (cm)}}{\mathrm{Height\ (cm)}}$$

TyG = ln[Fasting triglycerides (mg/dL) × Fasting blood glucose (mg/dL)/2]

$$\mathrm{TyG-BMI} = \mathrm{TyG} \times \mathrm{BMI}$$

$$\mathrm{TyG-WC} = \mathrm{TyG} \times \mathrm{WC}$$

$$\mathrm{TyG-Weight} = \mathrm{TyG} \times \mathrm{Weight}$$

$$\mathrm{TyG-WHtR} = \mathrm{TyG} \times \mathrm{WHtR}$$

Dependent variable

Hypertension was the dependent variable in this study. All subjects underwent standardized measurement procedures [36, 37]. In the Mobile Examination Center (MEC), participants were seated in a height-adjustable chair and remained still for five minutes prior to the measurement, maintaining an upright posture. Certified inspectors measured each participant's blood pressure three times consecutively (or four times if necessary) and recorded the readings. The average SBP and DBP were then calculated for analysis. According to the guidelines of ACC/AHA, hypertension was defined as SBP ≥ 130mmHg and/or DBP ≥ 80mmHg, whether the participants are untreated or receiving antihypertensive medication. Additionally, participants who reported a history of hypertension or the use of antihypertensive medications were also classified as hypertensive.

Covariates of interest

The covariates of interest selected for this study encompass demographic data (age, gender, race, PIR, education level, marital status), lifestyle factors (smoking and drinking), height, weight, BMI, WC, CHD, CHF, diabetes, serum biochemical components (glucose, triglycerides, sodium, potassium, creatinine), physical activity (sedentary activity), depression, and salt intakes (sodium and potassium). All data were collected through interviews conducted by trained and certified staff, while measurement indicators were obtained using standardized methods by trained medical personnel in the MEC.

Serum creatinine levels are measured using an enzymatic method involving creatininase with the Roche Cobas 6000 Chemistry Analyzer (Roche Diagnostics Corporation, Indianapolis, IN). Serum sodium is assessed through the Roche Cobas 6000 (c501 module) system, employing indirect ion-selective electrode (ISE) methodology. The concentration of serum potassium ions is determined by analyzing electrolyte activity in solution, using the indirect ISE method, where the specimen is diluted by the instrument before analysis. Physical activity levels are evaluated by monitoring daily sedentary time [12]. Data regarding sodium and potassium intake from the diet are extracted from the "Total Nutrient Intakes" file and calculated as a two-day average. Emotional state is assessed based on the presence of depression. The diagnosis of depression is scored using the Patient Health Questionnaire 9 (PHQ-9) scale, with a score greater than 10 indicating depression [38, 39].

Marital status was categorized as married/living with a partner or Other (including widowed, divorced, separated, never married). Education level was classified as less than high school, high school, and higher than high

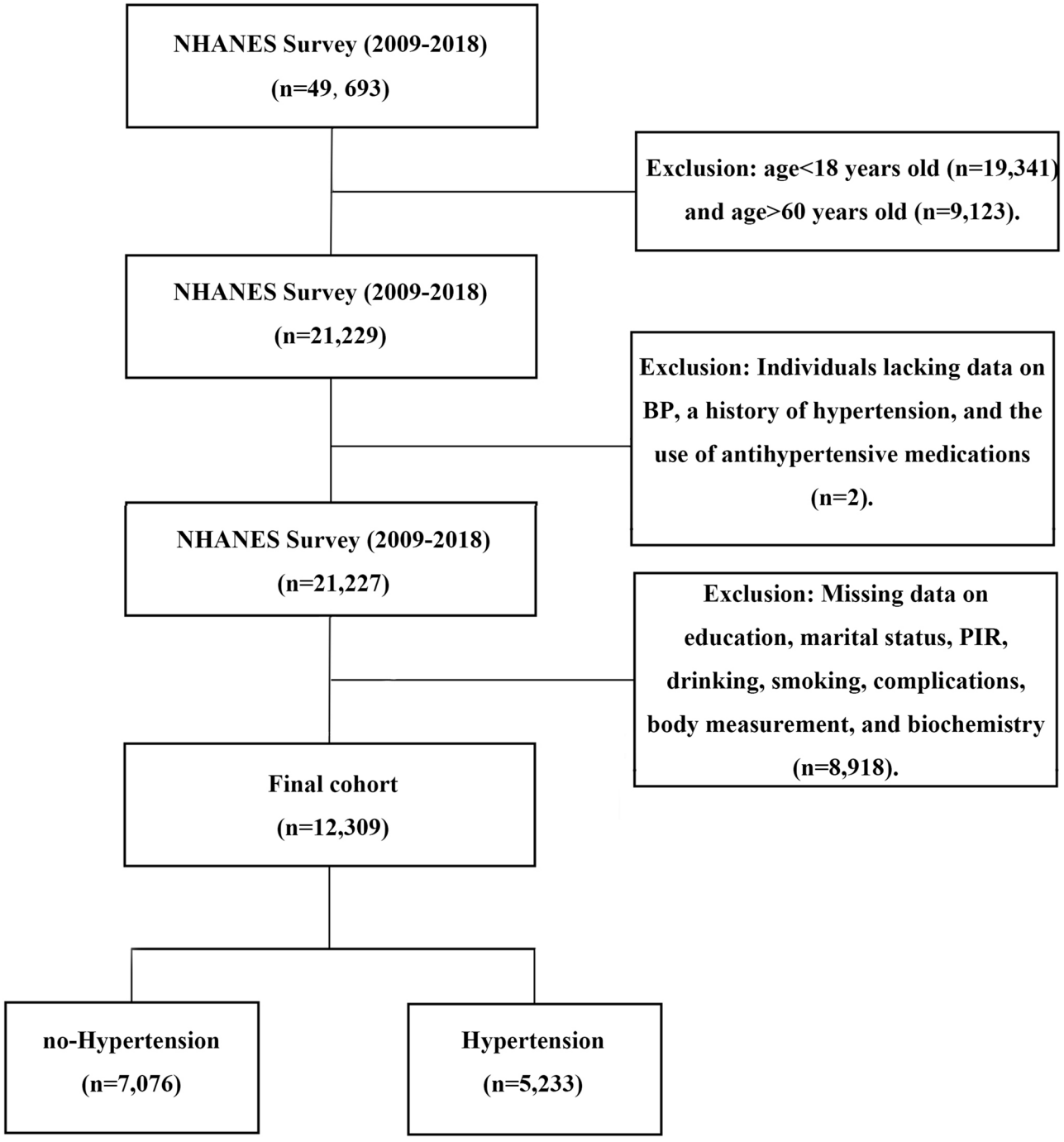

Fig. 1 Displays a detailed flow chart that the screening process utilized to select eligible participants in NHANES from 2009 to 2018

school. Race was categorized as Mexican American, Non-Hispanic Asian, Non-Hispanic Black, Non-Hispanic White, Other Hispanic, and Other Race (including Multi-Racial).

Participants were considered to have a history of drinking if they answered "yes" to the question, "Ever have 4/5 or more drinks every day?". Participants were considered to have a history of smoking if they answered "Yes" to the question, "Smoked at least 100 cigarettes in life?" Additionally, participants were considered to have related comorbidities if they answered "yes/borderline" to the question, "Have you ever been told by a doctor that you have CHD, CHF, or diabetes? "

Statistical analysis

All statistical analyses were performed in accordance with NHANES analytic guidelines [40]. Five waves of survey data (NHANES 2009–2018) were combined. All analyses were performed using R version 4.3.3. A two-sided *P*-value of less than 0.05 was considered statistically significant.

Data are presented as the mean ± SD or median (interquartile range) for continuous variables and frequencies (percentages) for categorical variables. The analysis of inter-group differences in continuous variables utilizes a complex survey design weighted linear regression model, with the Wald test performed on the regression coefficients. The comparison of categorical variables is conducted using the Rao-Scott corrected chi-square test.

The association between biomarkers and the prevalence of hypertension was evaluated using weighted multivariate logistic regression analysis, with results expressed as odds ratios (OR) and 95% confidence intervals (CI). To account for potential covariates, three models were developed: Model 1 was a crude model; Model 2 was adjusted for gender, age, race, and education; and Model 3 included further adjustments for gender, age, race, education, marital status, PIR, drinking, smoking, CHF, CHD, diabetes, depression, sedentary activity, serum biochemistry (sodium, potassium, and creatinine) and salt intake (sodium, and potassium). The restricted cubic spline (RCS) model was used to analyze the nonlinear relationship between biomarkers and hypertension. This model incorporated four knots located at the 5th, 35th, 65th, and 95th percentiles of the biomarkers. The plotted curve was adjusted for covariates like Model 3. When a nonlinear association was identified, segmented logistic regression analysis was performed to determine the inflection point.

Receiver Operating Characteristic (ROC) curves were generated to evaluate how effective biomarkers are in improving the detection of hypertension. The area under the curve (AUC), cut-off values, specificity, and sensitivity were recorded. Using the TyG-WHtR biomarker, which has the highest AUC, as a reference point, we compared it to other biomarkers using the DeLong test. Additionally, we calculated the net reclassification improvement (NRI) and integrated discrimination improvement (IDI) to evaluate the potential benefit of TyG-WHtR in enhancing the detection of hypertension.

Sensitivity analysis consists of two key aspects. First, the "Mice" package performs multiple imputations on the missing covariates in the original dataset, creating five distinct data sets for analysis and comparison. Second, subgroup analysis is conducted by organizing the data based on gender, race, education, marital status, drinking, smoking, CHD, CHF, and diabetes.

Results

Baseline characteristics

The baseline characteristics of the study population are detailed in Table 1. The average age of the participants was 40 years, with 6,324 males representing 51.38% of the total. The weighted incidence of hypertension in this population was 41.2%. Hypertension was more prevalent among older individuals, males, high school diplomas and below, married individuals, smokers, drinkers, and Non-Hispanic Black and Other Race - Including Multi-Racial. Additionally, those with higher measurements across various indices—such as height, weight, BMI, WC, WWI, WHtR, and the TyG indices—also exhibited a higher prevalence of hypertension. Moreover, the rates of CHF, CHD, diabetes, and depression are higher in the hypertensive group. Biochemical indicators, including glucose, triglycerides, and creatinine levels, were also elevated in individuals with hypertension. Individuals with higher sodium intake are more likely to develop hypertension.

Association of biomarkers with hypertension

A weighted multivariate logistic regression model was established using biomarkers as both a continuous and categorical variable to investigate its association with hypertension, respectively (Table 2). When analyzed as a continuous variable, the risk of hypertension increased per unit increase insignificantly in Weight (Model 1: OR = 1.01, 95% CI: 1.01–1.01), BMI (Model 1: OR = 1.02, 95% CI: 1.02–1.02), WC (Model 1: OR = 1.01, 95% CI: 1.01–1.01), TyG-BMI (Model 1: OR = 1.00, 95% CI: 1.00–1.00), TyG-WC (Model 1: OR = 1.00, 95% CI: 1.00–1.00), TyG-Weight (Model 1: OR = 1.00, 95% CI: 1.00–1.00), and these biomarkers were excluded from the subsequent analysis. WWI (Model 1: OR = 1.17, 95% CI: 1.15–1.19), WHtR (Model 1: OR = 4.26, 95% CI: 3.82–4.75), TyG (Model 1: OR = 1.20, 95% CI: 1.18–1.22), and TyG-WHtR (Model 1: OR = 1.16, 95% CI: 1.15–1.17) are significantly associated with hypertension risk. All of them showed a consistent association persisting in both the partially adjusted model (Model 2) and the fully adjusted model (Model 3) ($p < 0.001$). Furthermore, in the group comparison, using the lowest quartile of biomarkers as the reference, the risk of hypertension increased with higher quartiles of biomarkers (all P for trend < 0.001).

Nonlinear analysis

The RCS regression analysis was performed to elucidate the association between the four biomarkers (WWI, WHtR, TyG, and TyG-WHtR) and the OR for hypertension (Fig. 2). The adjusted multivariate regression model identified a positive nonlinear association between these four biomarkers and the OR of hypertension (p for overall < 0.001, p for nonlinear < 0.05).

Table 1 Baseline demographic characteristics

Variables	Total (*n* = 12,309)	no-Hypertension (*n* = 7,076)	Hypertension (*n* = 5,233)	*P* value
	***N* = 120,778,072**	***N* = 71,068,350**	***N* = 49,709,722**	
Age, years	39.97 ± 11.87	36.30 ± 11.20	44.93 ± 10.91	**< 0.001**
Male, n(%)	6,324 (51.38)	3,309 (46.76)	3,015 (57.62)	**< 0.001**
PIR, %	2.55 ± 1.66	2.56 ± 1.67	2.54 ± 1.66	0.606
Education, n(%)				**0.002**
Less than high school	676 (5.49)	386 (5.46)	290 (5.54)	
High school	4,289 (34.84)	2,326 (32.87)	1,963 (37.51)	
Higher than high school	7,344 (59.66)	4,364 (61.67)	2,980 (56.95)	
Marital Status, n(%)				**0.016**
Married	7,362 (59.81)	4,177 (59.03)	3,185 (60.86)	
Other	4,947 (40.19)	2,899 (40.97)	2,048 (39.14)	
Smoking, n(%)	5,591 (45.42)	2,982 (42.14)	2,609 (49.86)	**< 0.001**
Drinking, n(%)	2,034 (16.52)	1,003 (14.17)	1,031 (19.70)	**< 0.001**
Race, n(%)				**< 0.001**
Mexican American	1,861 (15.12)	1,184 (16.73)	677 (12.94)	
Non-Hispanic Asian	1,039 (8.44)	651 (9.20)	388 (7.41)	
Non-Hispanic Black	2,495 (20.27)	1,150 (16.25)	1,345 (25.70)	
Non-Hispanic White	5,151 (41.85)	3,021 (42.69)	2,130 (40.70)	
Other Hispanic	1,188 (9.65)	740 (10.46)	448 (8.56)	
Other Race - Including Multi-Racial	575 (4.67)	330 (4.66)	245 (4.68)	
SBP, mmHg	119.65 ± 15.56	111.71 ± 9.00	130.38 ± 16.11	**< 0.001**
DBP, mmHg	72.00 (64.67, 78.67)	68.00 (62.00, 73.33)	80.00 (72.00, 86.00)	**< 0.001**
CHF, n(%)	146 (1.19)	17 (0.24)	129 (2.47)	**< 0.001**
CHD, n(%)	158 (1.28)	31 (0.44)	127 (2.43)	**< 0.001**
Diabetes, n(%)				**< 0.001**
Yes	938 (7.62)	249 (3.52)	689 (13.17)	
No	11,148 (90.57)	6,746 (95.34)	4,402 (84.12)	
Borderline	223 (1.81)	81 (1.14)	142 (2.71)	
Depression, n(%)	972 (7.90)	461 (6.51)	511 (9.76)	**< 0.001**
Serum biochemical components				
Glucose, mg/dL	98.64 ± 35.66	93.32 ± 26.33	105.84 ± 44.32	**< 0.001**
Triglycerides, mg/dL	153.51 ± 135.51	134.92 ± 116.14	178.65 ± 154.47	**< 0.001**
Sodium, mmol/L	139.26 ± 2.26	139.27 ± 2.10	139.26 ± 2.46	0.111
Potassium, mmol/L	3.96 ± 0.32	3.96 ± 0.30	3.96 ± 0.34	0.521
Creatinine, umol/L	76.00 ± 29.05	73.11 ± 16.65	79.91 ± 39.79	**< 0.001**
Salt intake in diet				
Sodium intakes, mg/d	3,650.86 ± 1620.95	3,650.79 ± 1633.30	3,650.94 ± 1604.27	**0.001**
Potassium intakes, mg/d	2,656.44 ± 1136.70	2,661.37 ± 1150.37	2,649.78 ± 1118.03	0.106
Sedentary Activity, min/d	384.39 ± 471.72	377.84 ± 474.49	393.25 ± 467.86	0.490
Height, cm	168.50 (161.70, 175.80)	167.70 (161.10, 174.93)	169.70 (162.50, 176.90)	**< 0.001**
Weight, kg	83.91 ± 22.33	78.36 ± 19.15	91.42 ± 24.07	**< 0.001**
BMI, kg/m2	29.37 ± 7.20	27.67 ± 6.30	31.67 ± 7.69	**< 0.001**
WC, cm	97.00 (86.30, 108.90)	92.30 (82.70, 103.20)	103.30 (93.60, 115.70)	**< 0.001**
WWI	10.82 (10.29, 11.37)	10.65 (10.12, 11.18)	11.05 (10.58, 11.58)	**< 0.001**
WHtR	0.59 ± 0.10	0.56 ± 0.09	0.62 ± 0.10	**< 0.001**
TyG	8.60 (8.14, 9.10)	8.44 (8.02, 8.92)	8.82 (8.35, 9.32)	**< 0.001**
TyG-BMI	256.12 ± 72.05	236.83 ± 62.84	282.19 ± 75.44	**< 0.001**
TyG-WC	844.74 (718.07, 979.45)	784.04 (676.13, 905.86)	922.26 (807.05, 1054.05)	**< 0.001**
TyG-Weight	698.22 (570.14, 854.50)	643.14 (532.49, 779.09)	782.01 (646.07, 949.70)	**< 0.001**
TyG-WHtR	5.01 (4.26, 5.81)	4.66 (4.02, 5.40)	5.44 (4.77, 6.23)	**< 0.001**

"n" represents the original sample size, "N" represents the weighted sample size. *P* value is the weighted value

Abbreviation: PIR, poverty-to-income ratio; SBP, systolic blood pressure; DBP, diastolic blood pressure; CHF, chronic heart failure; CHD, coronary heart disease. BMI, body mass index; WC, waist circumference; WWI, weight-adjusted-waist index; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; TyG-BMI, triglyceride glucose-body mass index; TyG-WC, triglyceride glucose-waist circumference; TyG-Weight, triglyceride glucose-weight; TyG-WHtR, triglyceride glucose-waist to height ratio

Table 2 Weighted multivariable adjusted models of biomarkers associated with the prevalence of hypertension

	Model1		Model2		Model3	
	OR (95%CI)	***P* value**	**OR (95%CI)**	***P* value**	**OR (95%CI)**	***P* value**
Weight						
Continuous Per Unit Increase	1.01 (1.01 ~ 1.01)	**< 0.001**	1.01 (1.01 ~ 1.01)	**< 0.001**	1.01 (1.00 ~ 1.01)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.10 (1.06 ~ 1.13)	**< 0.001**	1.05 (1.02 ~ 1.08)	**0.003**	1.04 (1.01 ~ 1.07)	**0.005**
Q3	1.23 (1.20 ~ 1.27)	**< 0.001**	1.15 (1.12 ~ 1.19)	**< 0.001**	1.14 (1.11 ~ 1.18)	**< 0.001**
Q4	1.45 (1.41 ~ 1.49)	**< 0.001**	1.35 (1.31 ~ 1.39)	**< 0.001**	1.33 (1.29 ~ 1.37)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
BMI						
Continuous Per Unit Increase	1.02 (1.02 ~ 1.02)	**< 0.001**	1.02 (1.02 ~ 1.02)	**< 0.001**	1.02 (1.01 ~ 1.02)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.14 (1.11 ~ 1.18)	**< 0.001**	1.08 (1.05 ~ 1.11)	**< 0.001**	1.08 (1.05 ~ 1.11)	**< 0.001**
Q3	1.27 (1.23 ~ 1.31)	**< 0.001**	1.17 (1.14 ~ 1.21)	**< 0.001**	1.17 (1.13 ~ 1.21)	**< 0.001**
Q4	1.46 (1.41 ~ 1.50)	**< 0.001**	1.38 (1.33 ~ 1.42)	**< 0.001**	1.35 (1.30 ~ 1.40)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
WC						
Continuous Per Unit Increase	1.01 (1.01 ~ 1.01)	**< 0.001**	1.01 (1.00 ~ 1.01)	**< 0.001**	1.01 (1.01 ~ 1.01)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.13 (1.10 ~ 1.16)	**< 0.001**	1.06 (1.03 ~ 1.09)	**< 0.001**	1.06 (1.03 ~ 1.09)	**< 0.001**
Q3	1.32 (1.28 ~ 1.36)	**< 0.001**	1.20 (1.16 ~ 1.24)	**< 0.001**	1.19 (1.15 ~ 1.23)	**< 0.001**
Q4	1.51 (1.46 ~ 1.56)	**< 0.001**	1.36 (1.32 ~ 1.41)	**< 0.001**	1.34 (1.29 ~ 1.39)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
WWI						
Continuous Per Unit Increase	1.17 (1.15 ~ 1.19)	**< 0.001**	1.14 (1.12 ~ 1.16)	**< 0.001**	1.12 (1.10 ~ 1.14)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.15 (1.12 ~ 1.18)	**< 0.001**	1.09 (1.06 ~ 1.12)	**< 0.001**	1.09 (1.06 ~ 1.12)	**< 0.001**
Q3	1.24 (1.20 ~ 1.28)	**< 0.001**	1.15 (1.12 ~ 1.19)	**< 0.001**	1.14 (1.10 ~ 1.18)	**< 0.001**
Q4	1.39 (1.35 ~ 1.43)	**< 0.001**	1.30 (1.26 ~ 1.35)	**< 0.001**	1.26 (1.22 ~ 1.31)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
WHtR						
Continuous Per Unit Increase	4.26 (3.82 ~ 4.75)	**< 0.001**	3.48 (3.08 ~ 3.92)	**< 0.001**	3.21 (2.81 ~ 3.66)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.17 (1.13 ~ 1.21)	**< 0.001**	1.09 (1.05 ~ 1.12)	**< 0.001**	1.09 (1.05 ~ 1.12)	**< 0.001**
Q3	1.31 (1.27 ~ 1.35)	**< 0.001**	1.20 (1.16 ~ 1.24)	**< 0.001**	1.19 (1.15 ~ 1.23)	**< 0.001**
Q4	1.49 (1.44 ~ 1.54)	**< 0.001**	1.39 (1.34 ~ 1.44)	**< 0.001**	1.36 (1.31 ~ 1.41)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
TyG						
Continuous Per Unit Increase	1.20 (1.18 ~ 1.22)	**< 0.001**	1.15 (1.13 ~ 1.17)	**< 0.001**	1.12 (1.10 ~ 1.14)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.12 (1.04 ~ 1.09)	**< 0.001**	1.08 (1.04 ~ 1.12)	**< 0.001**	1.07 (1.03 ~ 1.11)	**0.004**
Q3	1.27 (1.13 ~ 1.19)	**< 0.001**	1.19 (1.16 ~ 1.23)	**< 0.001**	1.18 (1.14 ~ 1.21)	**< 0.001**
Q4	1.42 (1.22 ~ 1.28)	**< 0.001**	1.29 (1.25 ~ 1.34)	**< 0.001**	1.25 (1.20 ~ 1.29)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**0.002**	
TyG-BMI						
Continuous Per Unit Increase	1.00 (1.00 ~ 1.00)	**< 0.001**	1.00 (1.00 ~ 1.00)	**< 0.001**	1.00 (1.00 ~ 1.00)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	

Table 2 (continued)

	Model1		Model2		Model3	
	OR (95%CI)	*P* value	OR (95%CI)	*P* value	OR (95%CI)	*P* value
Q2	1.17 (1.14 ~ 1.21)	**< 0.001**	1.10 (1.07 ~ 1.13)	**< 0.001**	1.10 (1.07 ~ 1.13)	**< 0.001**
Q3	1.32 (1.27 ~ 1.36)	**< 0.001**	1.21 (1.17 ~ 1.26)	**< 0.001**	1.21 (1.17 ~ 1.25)	**< 0.001**
Q4	1.52 (1.47 ~ 1.57)	**< 0.001**	1.41 (1.36 ~ 1.45)	**< 0.001**	1.38 (1.33 ~ 1.42)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
TyG-WC						
Continuous Per Unit Increase	1.00 (1.00 ~ 1.00)	**< 0.001**	1.00 (1.00 ~ 1.00)	**< 0.001**	1.00 (1.00 ~ 1.00)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.15 (1.11 ~ 1.19)	**< 0.001**	1.08 (1.05 ~ 1.12)	**< 0.001**	1.08 (1.05 ~ 1.12)	**< 0.001**
Q3	1.35 (1.30 ~ 1.40)	**< 0.001**	1.23 (1.19 ~ 1.28)	**< 0.001**	1.22 (1.18 ~ 1.27)	**< 0.001**
Q4	1.57 (1.52 ~ 1.63)	**< 0.001**	1.42 (1.37 ~ 1.47)	**< 0.001**	1.39 (1.34 ~ 1.44)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
TyG-Weight						
Continuous Per Unit Increase	1.00 (1.00 ~ 1.00)	**< 0.001**	1.00 (1.00 ~ 1.00)	**< 0.001**	1.00 (1.00 ~ 1.00)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.13 (1.10 ~ 1.17)	**< 0.001**	1.09 (1.06 ~ 1.12)	**< 0.001**	1.08 (1.05 ~ 1.11)	**< 0.001**
Q3	1.29 (1.25 ~ 1.33)	**< 0.001**	1.20 (1.17 ~ 1.24)	**< 0.001**	1.19 (1.15 ~ 1.23)	**< 0.001**
Q4	1.53 (1.49 ~ 1.58)	**< 0.001**	1.42 (1.37 ~ 1.46)	**< 0.001**	1.39 (1.34 ~ 1.44)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	
TyG-WHtR						
Continuous Per Unit Increase	1.16 (1.15 ~ 1.17)	**< 0.001**	1.13 (1.12 ~ 1.14)	**< 0.001**	1.12 (1.11 ~ 1.14)	**< 0.001**
Categorical						
Q1	1.00 (Reference)		1.00 (Reference)		1.00 (Reference)	
Q2	1.16 (1.08 ~ 1.14)	**< 0.001**	1.09 (1.06 ~ 1.12)	**< 0.001**	1.09 (1.06 ~ 1.12)	**< 0.001**
Q3	1.34 (1.19 ~ 1.25)	**< 0.001**	1.23 (1.18 ~ 1.28)	**< 0.001**	1.22 (1.18 ~ 1.27)	**< 0.001**
Q4	1.54 (1.34 ~ 1.41)	**< 0.001**	1.41 (1.37 ~ 1.46)	**< 0.001**	1.38 (1.33 ~ 1.43)	**< 0.001**
P for trend	**< 0.001**		**< 0.001**		**< 0.001**	

Model1: Crude

Model2: Adjust: Gender, Age, Race, Education

Model3: Adjust: Gender, Age, Race, Education, Marital status, PIR, Drinking, Smoking, CHF, CHD, Diabetes, Depression, Sedentary Activity, Serum biochemistry (sodium, potassium, and creatinine) and Salt intake (sodium, and potassium)

Abbreviation: OR, Odds Ratio, CI, Confidence Interval; BMI, body mass index; WC, waist circumference; WWI, weight-adjusted-waist index; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; TyG-BMI, triglyceride glucose-body mass index; TyG-WC, triglyceride glucose-waist circumference; TyG-Weight, triglyceride glucose-weight; TyG-WHtR, triglyceride glucose-waist to height ratio; PIR, poverty-to-income ratio; CHF, chronic heart failure; CHD, coronary heart disease

Segmented regression identified a significant threshold effect at TyG-WHtR = 5.79 (P for likelihood ratio test < 0.001). Below this threshold, each unit increase in TyG-WHtR was associated with 96% higher odds of hypertension (OR = 1.96, 95%CI:1.82–2.12). Above the threshold, the association remained positive but attenuated (OR = 1.54, 95%CI:1.36–1.76). WWI, WHtR, and TyG also showed similar threshold effects (Table 3).

Receiver operating characteristic analysis

ROC analysis was employed to assess the value of the four biomarkers to refine the detection of prevalent hypertension (Table 4). The AUC of TyG-WHtR for the detection of prevalent hypertension was 0.6946 (95%CI: 0.6853–0.7039), significantly higher than that of other biomarkers ($P < 0.001$), which showed the most potent predictive performance (Fig. 3, and Figure S1 in supplement file). The results from the NRI/IDI indicated that the predictive ability of the other three biomarkers for hypertension was reduced compared to that of TyG-WHTR.

Sensitivity analysis

After analyzing the data from multiple imputations, the results indicated that in the five datasets, the four biomarkers of WWI, WHtR, TyG, and TyG-WHtR were significantly associated with hypertension, with TyG-WHtR demonstrating the best predictive performance (Tables S1, and Figure S1 in supplement file).

The impact of TyG-WHtR on hypertension was further stratified and analyzed across different subgroups (Fig. 4). The analysis demonstrated that the primary findings remained robust across subgroups defined by gender, race, education level, marital status, drinking, smoking, CHF, and diabetes, with all P for interaction > 0.05.

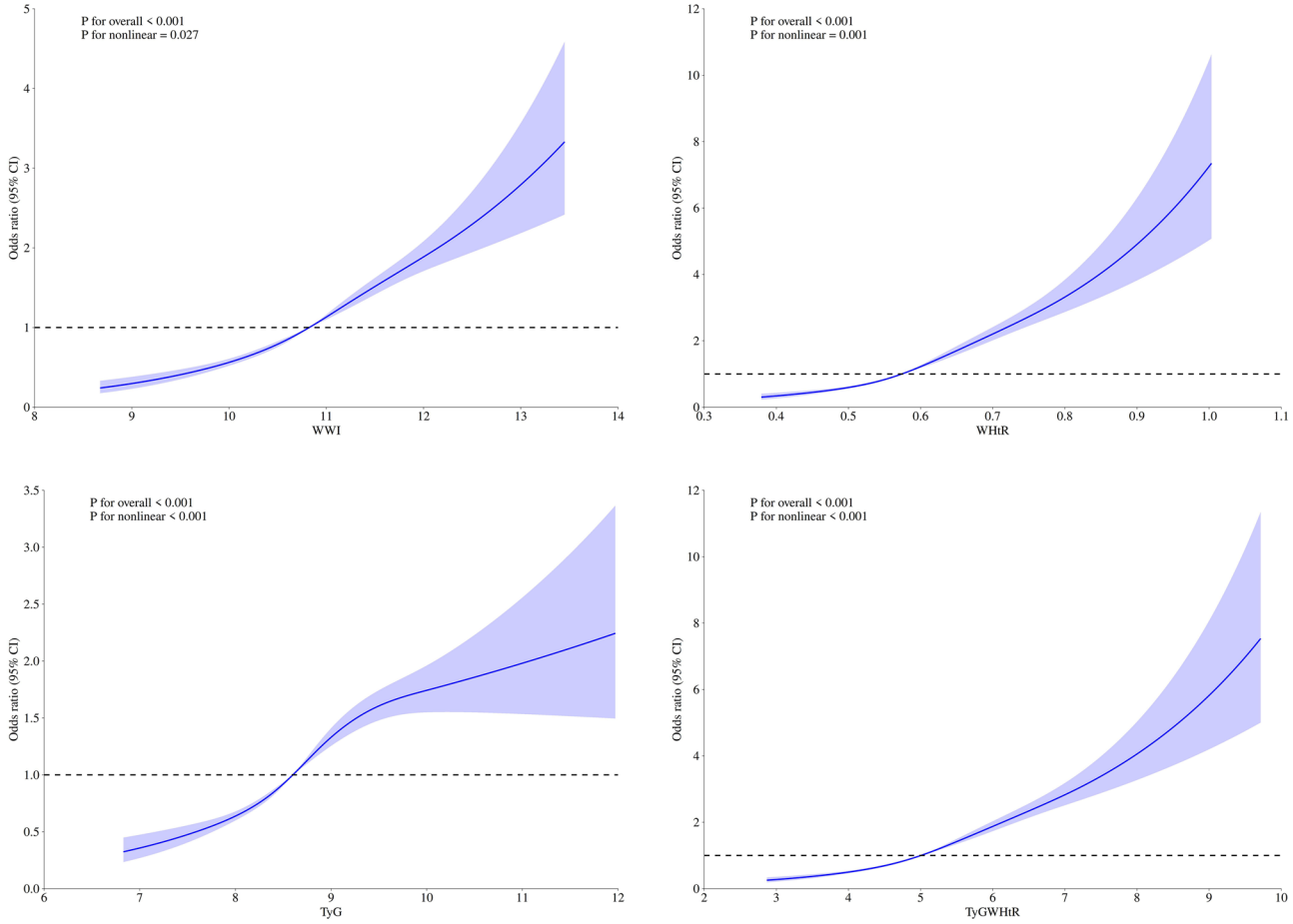

Fig. 2 Dose-response relationship between WWI/WHtR/TyG/TyG-WHtR and the risk of hypertension. The solid line represents the OR value, and the shadow represents 95% CI. **Abbreviation**: OR, odds ratio; CI, Confidence Interval; TyG, triglyceride-glucose; TyG-Weight, triglyceride glucose-weight; TyG-WHtR, triglyceride glucose-waist to height ratio; WWI, weight-adjusted-waist index; WHtR, waist-to-height ratio

Discussion

The research results indicated that there was a strong positive nonlinear association between WWI/WHtR/TyG/TyG-WHtR and the risk of hypertension in American adults age 18–60. TyG-WHtR showed the best predictive performance. For every unit increase in TyG-WHtR, the risk of hypertension in the population rises by 12%.

Hypertension now affects one-third of the total population, significantly raising the risk of heart, brain, kidney, and other diseases, and it has become the leading cause of premature death worldwide [41]. Therefore, early prediction and timely intervention are essential for the prevention of hypertension. Elderly patients frequently experience ISH, which is associated with the age-related loss of arterial elasticity, making it more challenging to treat than primary hypertension [15]. The relationship between obesity and hypertension in elderly individuals is often complicated by a reduction in muscle mass and the accumulation and redistribution of visceral fat [42]. These factors make it more complex and challenging to understand the causes of obesity-related hypertension in elderly. On the contrary, younger adults are less likely to have other chronic diseases, so metabolic problems such as obesity and hyperlipidemia are one of the main factors causing adult hypertension [43]. Therefore, biomarkers that apply to young people may not necessarily apply to the elderly. Currently, the prevalence of obesity and overweight among adults in the United States has surpassed 70%, highlighting the need for attention to the resultant hypertension issue [44].

In individuals with obesity, the dysfunction of adipocytes results in systemic IR. This dysfunction also affects the sympathetic nervous system and the renin-angiotensin-aldosterone system (RAAS). Consequently, there is a contraction of vascular smooth muscle and retention of water and sodium, which contributes to an increase in blood pressure. Over time, elevated cardiac output and blood volume can lead to increased systemic vascular resistance [45]. Research shows that obese hypertensive patients have higher renal sodium reabsorption compared to non-obese hypertensive patients, along with

Table 3 Effect of biomarkers level on hypertension: adjusted OR from segmented logistics regression analysis

	Adjusted OR (95%CI)	*P*
WWI		
Model 1 Fitting model by standard logistics regression	1.83 (1.72–1.94)	**< 0.001**
Model 2 Fitting model by two-piecewise logistics regression		
Inflection point	12.05	
<12.05	1.91 (1.78 ~ 2.05)	**< 0.001**
≥12.05	1.13 (0.71 ~ 1.78)	0.586
P for likelihood test		**0.015**
WHtR		
Model 1 Fitting model by standard logistics regression	404.70 (255.95–639.91)	**< 0.001**
Model 2 Fitting model by two-piecewise logistics regression		
Inflection point	0.65	
<0.65	1099.78 (473.96 ~ 2551.94)	**< 0.001**
≥0.65	77.76 (22.35 ~ 270.56)	**< 0.001**
P for likelihood test		**0.002**
TyG		
Model 1 Fitting model by standard logistics regression	1.70 (1.60–1.81)	**< 0.001**
Model 2 Fitting model by two-piecewise logistics regression		
Inflection point	9.03	
<9.03	2.09 (1.87 ~ 2.35)	**< 0.001**
≥9.03	1.25 (1.07 ~ 1.46)	**0.005**
P for likelihood test		**< 0.001**
TyG-WHtR		
Model 1 Fitting model by standard logistics regression	1.80 (1.73–1.88)	**< 0.001**
Model 2 Fitting model by two-piecewise logistics regression		
Inflection point	5.79	
<5.79	1.99 (1.84 ~ 2.15)	**< 0.001**
≥5.79	1.49 (1.32 ~ 1.69)	**< 0.001**
P for likelihood test		**< 0.001**

OR was adjusted for Gender, Age, Race, Education, Marital status, PIR, Drinking, Smoking, CHF, CHD, Diabetes, Depression, Sedentary Activity, Serum biochemistry (sodium, potassium, and creatinine) and Salt intake (sodium, and potassium)

Abbreviation: OR, Odds Ratio, CI, Confidence Interval; WWI, weight-adjusted-waist index; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; TyG-WHtR, triglyceride glucose-waist to height ratio; PIR, poverty-to-income ratio; CHF, chronic heart failure; CHD, coronary heart disease

Table 4 ROC curves for biomarkers to improve the identification of hypertension

	WWI	WHtR	TyG	TyG-WHtR
AUC (95%CI)	0.6469 (0.6372–0.6566)	0.6755 (0.6660–0.6850)	0.6466 (0.6189–0.6416)	0.6946 (0.6853–0.7039)
P for AUC	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Cut-off Value	10.601	0.561	8.587	4.831
Specificity	0.478	0.558	0.587	0.565
Sensitivity	0.739	0.708	0.637	0.728
P for comparison	**< 0.001**	**< 0.001**	**< 0.001**	Reference
NRI, Categorical (95%CI)	−0.1703 (−0.1866 -−0.1541)	−0.0667 (−0.0792 -−0.0542)	−0.172 (−0.1898 -−0.1542)	Reference
P	**< 0.001**	**< 0.001**	**< 0.001**	
NRI, Continuous (95%CI)	−0.3996 (−0.4346 -−0.3646)	−0.3458 (−0.3809 -−0.3107)	−0.3591 (−0.3941 -−0.3241)	Reference
P	**< 0.001**	**< 0.001**	**< 0.001**	
IDI (95%CI)	−0.0468 (−0.0504 -−0.0433)	−0.0216 (−0.0238 -−0.0193)	−0.0468 (−0.0512 -−0.0424)	Reference
P	**< 0.001**	**< 0.001**	**< 0.001**	

Abbreviation: ROC, Receiver operating characteristic; AUC, Area under the curve; CI, Confidence Interval; WWI, weight-adjusted-waist index; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; TyG-WHtR, triglyceride glucose-waist to height ratio. NRI, net reclassification improvement; IDI, integrated discrimination improvement

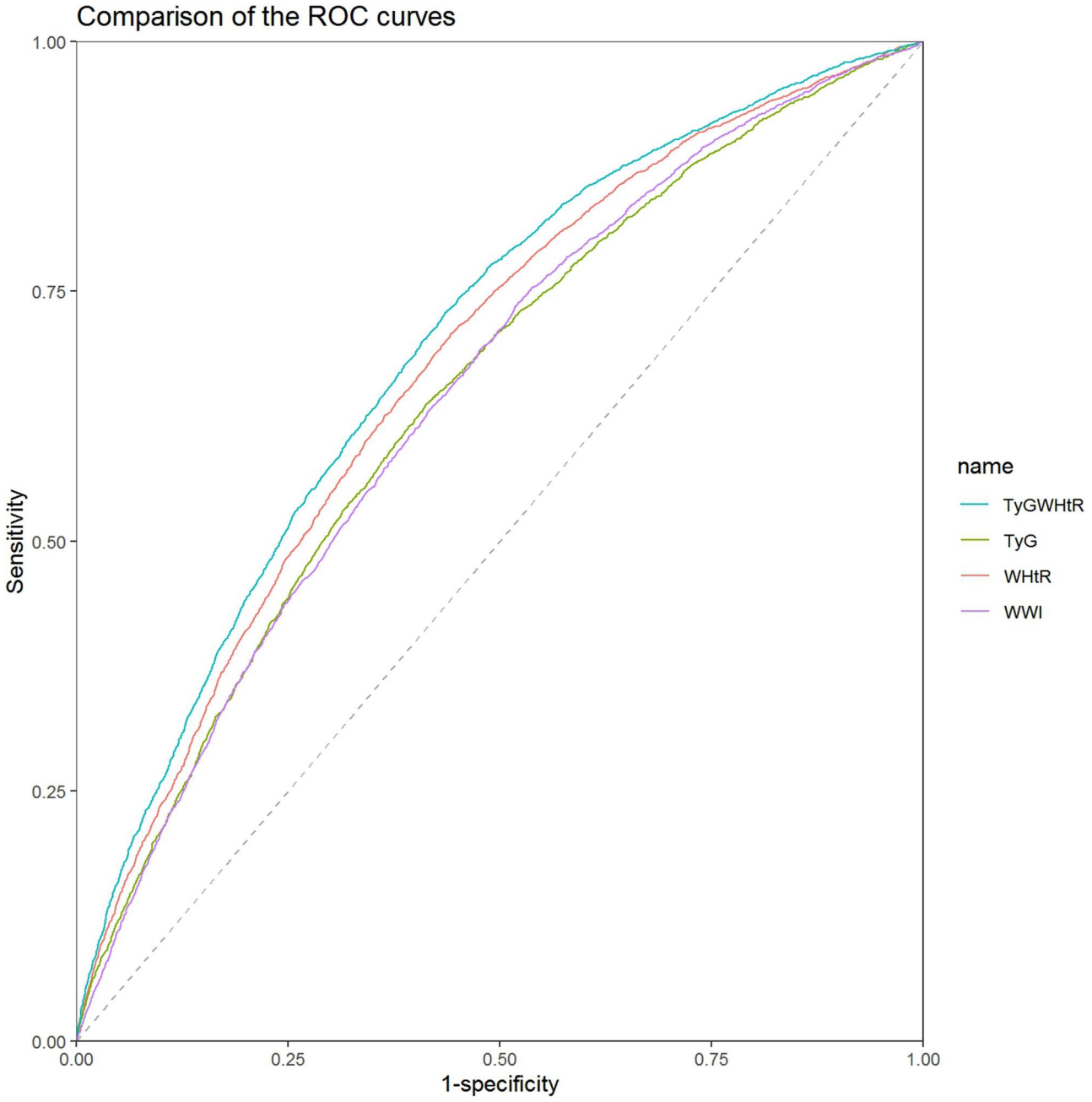

Fig. 3 Comparison of the ROC curves of WWI, WHtR, TyG and TyG-WHtR in total participants. **bbreviation**: ROC, receiver operating characteristic; WWI, weight-adjusted-waist index; WHtR, waist-to-height ratio; TyG, triglyceride-glucose; TyG-WHtR, triglyceride glucose-waist to height ratio

increased fluid volume, plasma volume, and intracellular fluid volume [46]. Visceral adipose tissue exhibits resistance to insulin and leptin. It alters the secretion of various molecules and hormones, including adiponectin, leptin, resistin, tumor necrosis factor, and interleukin-6, which can worsen cardiovascular diseases linked to obesity [47]. This suggests that the prediction of hypertension in younger adults can be determined by the obesity index.

There are currently many biomarkers used for the early prediction of hypertension. Accumulated evidence suggests that traditional biomarkers, such as BMI, WC, and WHtR, can help public health officials develop strategies to prevent hypertension in the population [48–51]. These traditional biomarkers have proven to be practical tools for outpatient screening of hypertension [52]. However, due to the inability of traditional obesity biomarkers to accurately distinguish between fat body mass and lean body mass, they cannot accurately reflect the

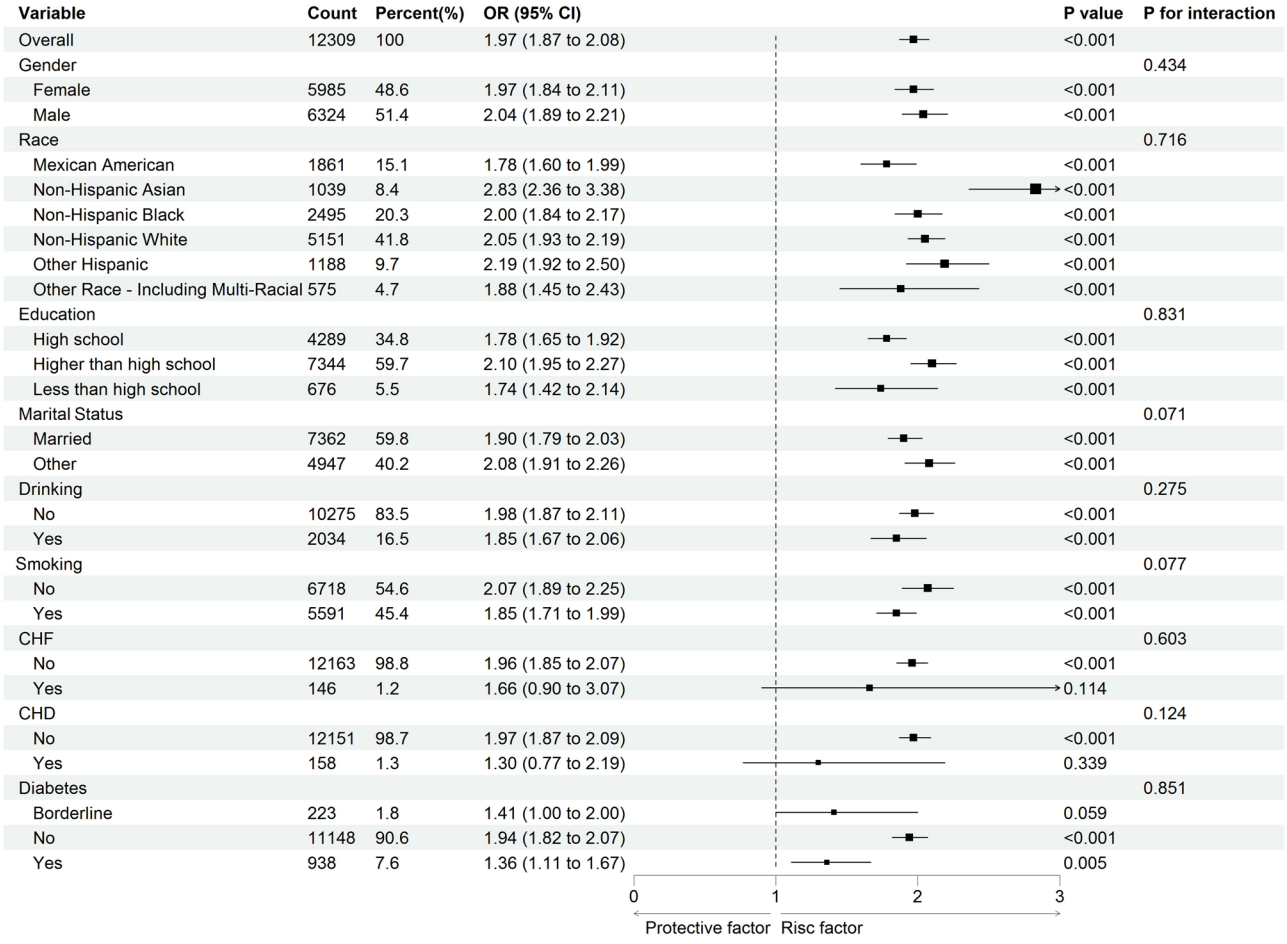

Fig. 4 The results of subgroup analysis demonstrate the association between TyG-WHtR and the prevalence of hypertension in adults. The Weighted Logistic regression models were used in both subgroup analysis and forest mapping. The interaction analysis adopts likelihood ratio test. **Abbreviations**: PIR, poverty-to-income ratio; BMI, body mass index; CHF, Chronic heart failure; CHD, coronary heart disease; OR, odds ratio; CI, confidence interval

metabolic status of the body, which leads to the inability of traditional biomarkers to accurately reflect the risk of hypertension and CVD in the population. Individuals with high values of weight, BMI, and WC do not face an increased risk of CVD and hypertension, a phenomenon often referred to as the "obesity paradox" in clinical practice [53, 54]. This paradox is universal and is not affected by gender, age, race, or type of disease [55, 56]. Our research has confirmed this phenomenon. Both univariate and multivariate analyses indicate almost no association between BMI, weight, WC, and hypertension, with an OR of approximately 1. This suggests that an increase in each of these biomarkers has less than a 1% impact on the risk of developing hypertension. As a result, related derivative biomarkers—such as TyG-BMI, TyG-WC, and TyG-Weight—also show that their association with hypertension has nearly vanished. Due to this contradiction, the clinical application of these biomarkers has been limited. Therefore, we need to identify more effective biomarkers for predicting the risk of hypertension in a clinical setting.

WHtR and WWI are relatively new biomarkers that have shown a strong association with hypertension, and our research supports this finding [23, 57]. Moreover, we observed that the association between TyG/TyG-WHtR and adult hypertension in the United States is also particularly significant. Our study compared the parameters of WHtR, WWI, TyG, and TyG-WHtR, revealing that TyG-WHtR has the strongest association with hypertension risk. Li et al.'s research on the Chinese population shows that TyG-WHtR has the best prediction effect, consistent with our research results [58]. Several biomarkers can predict the risk of hypertension, but their predictive effect is generally moderate, ranging from 0.5 to 0.6 [52, 58, 59]. However, our results showed that TyG-WHtR has a predictive performance of nearly 0.7 for the risk of hypertension in younger adults in the United States, making it a relatively high-quality indicator currently discovered. Additionally, sensitivity analysis results demonstrated a robust association between TyG-WHtR and hypertension across various subgroups. Therefore,

TyG-WHtR has stable and reliable advantages in predicting the occurrence of hypertension.

In 2008, Simental et al. first introduced the TyG index, a novel and easily measurable biomarker for assessing the degree of IR in otherwise healthy individuals [60]. Subsequent studies have demonstrated that TyG outperforms other biomarkers, such as HOMA-IR, in evaluating IR [61]. The TyG index incorporates triglyceride and glucose levels, allowing it to simultaneously reflect the body's fat metabolism state. Consequently, TyG serves as a marker for CVD and atherosclerosis and is associated with all-cause mortality in the population [62]. IR can cause renal sodium retention, activate RAAS, enhance sympathetic nerve activity, promote endothelial dysfunction, and increase peripheral and renal vascular resistance. Regarding obesity-related hypertension, IR may have a synergistic effect on the obesity-hypertension association by increasing adipokine secretion and sympathetic nervous system activity [63], which explains the fundamental mechanism by which TyG can reflect the risk of hypertension in the population. When compared to BMI and WC, the WHtR is regarded as a more effective method for identifying abdominal obesity, as it takes both WC and height into account [64]. The combination of TyG and WHtR into the TyG-WHtR index leverages the strengths of both markers, providing a better reflection of the body's metabolic situation [65]. Elevated TyG levels indicate an increase in the body's IR, enhanced activation of the RAAS and the sympathetic nervous system, as well as increased arterial stiffness, all of which are linked to hypertension [33, 66, 67].

With numerous biomarkers available for predicting hypertension, managing all biomarkers will require significant financial resources and energy. TyG-WHtR is consistently reliable in predicting hypertension in younger adults, making it valuable for clinical use. TyG-WHtR combines WHtR's capacity to assess obesity with the TyG's ability to reflect in vivo IR. This combined approach provides a more comprehensive view of the metabolic status in the body and is significantly associated with hypertension. Therefore, adopting TyG-WHtR as a predictive indicator can aid in developing effective hypertension management strategies.

Strengths and limitations

Firstly, this study utilized 10 years of NHANES data, retaining relatively complete information from 12,309 participants through a careful selection of inclusion and exclusion criteria, which ensured the statistical validity of the sample. Secondly, to avoid bias caused by deleting missing data, we additionally applied multiple imputations to generate 5 datasets and analyzed them separately. The results showed consistency, further proving the reliability of the conclusion. Thirdly, the interviewees were chosen through stratified sampling and other methods, allowing for a representation of the adult population in the United States, thus ensuring the results' representativeness and generalizability. Fourthly, the covariates we included include multidimensional data such as physical characteristics, clinical diseases, biochemical indicators, emotional status, physical activity, and dietary salt intake. Factors that may affect the risk of hypertension were widely included, and after adjusting for multiple factors, the results remained robust, indicating the reliability of the conclusion. Lastly, the TyG-WHtR parameter is straightforward to obtain and calculate, making it practical for clinical application.

However, several limitations of this study should be acknowledged. Firstly, as a cross-sectional study, we can only confirm an association between TyG-WHtR and hypertension. Further prospective cohort studies are necessary to clarify the causal relationship between TyG-WHtR and hypertension. Secondly, although we had adjusted for multiple covariates, other potential variables that are not yet clear may still affect our results, which requires further research to explore in the future. Thirdly, despite our efforts to incorporate multiple biomarkers, TyG-WHtR showed the best predictive performance, but its AUC value was around 0.7, indicating moderate predictive performance. In the future, it is necessary to continue exploring better predictive biomarkers for clinical application. Lastly, this study focuses on younger adults aged 18 to 60 in the United States, so its applicability to younger adults in other countries requires further investigation through corresponding research.

Conclusion

This study found a significant association between TyG-WHtR and hypertension in American adults aged 18 to 60. This finding could assist public health departments in improving blood pressure management strategies.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12872-025-04853-y.

Supplementary Material 1
Supplementary Material 2
Supplementary Material 3
Supplementary Material 4
Supplementary Material 5
Supplementary Material 6
Supplementary Material 7
Supplementary Material 8

Author contributions
The dataset was collected and extract by HJW and LLX. Data were interpreted and analyzed by PGY and ZLP with help from CJZ. WJR provides conceptualization and formulas. WZW, WCF, CJB contributed software support and statistical analysis. The manuscript was drafted by HJW, LB and CJZ. LLX revision, language polishing, and support for manuscript submission. All authors read and approved the final manuscript. HJW and CJZ contributed to this work equally and should be considered as first co-authors.

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Data availability
All data used in this study are publicly available on the NHANES official website (https://wwwn.cdc.gov/nchs/nhanes).

Declarations

Ethics approval and consent to participate
The National Health and Nutrition Examination Survey (NHANES) protocol was approved by the National Center for Health Statistics Institutional Ethics Review Board, and the current study did not involve any personally identifiable information, thus exempting it from further ethical review.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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