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ORIGINAL RESEARCH

Exploring the Association Between Triglyceride-Glucose Indices and Their Derivatives With Obstructive Sleep Apnea: Insights From the National Health and Nutrition Examination Survey

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Background: Simple and affordable methods for evaluating Insulin Resistance (IR) have been suggested, such as the Triglyceride-Glucose (TyG) index and its variants, including the TyG-Body Mass Index (TyG-BMI), TyG-Waist Circumference (TyG-WC), and TyG-Waist-to-Height Ratio (TyG-WHtR). The aim of this study is to investigate the relationship between these TyG-related indices, which measure IR, and Obstructive Sleep Apnea (OSA).

Methods: This study analyzed NHANES data from 2007–2008, 2015–2016, and 2017–2020. TyG and its derivatives were evaluated as continuous and categorical variables in relation to OSA using multivariable logistic regression models. Subgroup analyses, dose-response relationships, and threshold effects were explored, and the diagnostic performance of TyG-related indices was assessed using AUC curves.

Results: The study included 8,374 participants. The fully adjusted Model 3 analysis (Note: Body Mass Index was not adjusted for TyG-BMI) of continuous variables showed a positive correlation between OSA and all four indices. All four TyG-related indicators showed statistically significant relationships with OSA when grouped into quartiles (TyG: AOR = 1.448, 95% CI: 1.260–1.663; TyG-BMI: AOR = 3.785, 95% CI: 3.319–4.317; TyG-WC: AOR = 2.089, 95% CI: 1.629–2.677; TyG-WHtR: AOR = 1.913, 95% CI: 1.548–2.363). Subgroup analysis revealed a stronger association of TyG-WHtR with OSA in the 41–59 age group (AOR = 1.459, 95% CI: 1.254–1.698) and the low-income group (AOR = 1.451, 95% CI: 1.241–1.698). TyG showed a linear relationship with OSA, while TyG-BMI, TyG-WC, and TyG-WHtR exhibited nonlinear relationships. The diagnostic capability was highest for TyG-WC, with an AUC of 0.647.

Conclusion: The study confirms strong associations between OSA and the TyG indices, particularly TyG-WC, which demonstrates significant predictive power for OSA risk. Future longitudinal studies are recommended to further investigate these associations and enhance OSA management in resource-constrained environments.

Keywords: triglyceride-glucose index, insulin resistance, epidemiological study, metabolic indices, obstructive sleep apnea

Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent upper airway obstructions, either partial (hypopnea) or complete (apnea), leading to intermittent hypoxia and frequent awakenings. Symptoms include daytime sleepiness, fatigue, loud gasping or snoring during sleep, and reduced or paused airflow.[1] The prevalence of OSA in adults is increasing, affecting approximately 26.6% of men and 9.4% of women, particularly in the context of rising obesity rates.[2] OSA has been closely linked to numerous serious diseases, including hypertension, coronary artery disease, stroke, and diabetes mellitus.[3] OSA-related medical costs and productivity losses are estimated to amount to billions of dollars

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annually in the United States,[4] highlighting the urgent need for increased awareness, early detection, and effective intervention.

Insulin resistance (IR), a key feature of metabolic syndrome, is characterized by a reduced response to insulin. The hyperinsulinemic-euglycemic clamp (HEC) test is the gold standard for identifying IR, but its invasiveness and complexity limit its practical use.[5] A newer, more practical and cost-effective method for assessing IR is the triglyceride-glucose (TyG) index, which combines levels of triglycerides and glucose.[6–10] Based on these findings, several derivative indices of TyG have been developed, such as TyG index based on waist circumference (TyG-WC), body mass index (TyG-BMI), and waist-to-height ratio (TyG-WHtR), offering a more comprehensive reflection of metabolic status.[11] For instance, TyG-WC reflects abdominal fat distribution,[12] while the TyG-BMI provides a more individualized assessment of metabolic risk.[13] These derivatives address some limitations of the classic TyG index, potentially offering a more comprehensive perspective for evaluating OSA risk.

Evidence indicates a strong connection between IR, metabolic syndrome, and OSA, as they share common metabolic and inflammatory mechanisms.[14,15] While the majority of research has concentrated mostly on the TyG index itself, paying little attention to the connection between its derivatives and OSA.[16–18] Furthermore, the dose-response relationships between these derivative indices and OSA, as well as their subgroup-specific performance, remain insufficiently studied.

OSA is a multifactorial condition, and early detection and risk assessment are critical for improving patient outcomes. However, diagnostic methods such as polysomnography are complex and costly, posing challenges for resource-limited settings.[19] The TyG index and its derivatives, as simple and accessible metabolic markers requiring only routine blood tests and basic physical measurements, are particularly suitable for use in community and primary care environments. Evaluating the potential utility of these indices in assessing OSA risk could provide cost-effective and practical solutions for clinical practice.

Although the association between the classic TyG index and OSA has been previously investigated, the roles of derivative indices such as TyG-BMI, TyG-WC, and TyG-WHtR in OSA risk assessment remain unclear. Using data from the National Health and Nutrition Examination Survey (NHANES), this study systematically evaluates the associations between these indices and OSA, aiming to provide novel insights into their potential applications in clinical and research settings.

Materials and Methods

Research Design and Study Population

The NHANES is a nationwide cross-sectional survey designed to assess the nutritional and health conditions of individuals in the United States. This study utilized NHANES data collected during 2007–2008, 2015–2016, and 2017–2020, with an initial total sample of 35,680 participants. Participants were excluded for the following reasons: missing OSA data (n = 12,614), missing triglyceride (TG) data (n = 13,420), missing body mass index (BMI) data (n = 452), and age under 20 years (n = 820). Participants under 20 years were excluded to ensure the analysis focused on the adult population, consistent with epidemiological standards and NHANES conventions. The final analysis included 8,374 participants, as shown in Figure 1.

OSA Assessment

According to previous studies using NHANES data,[15] a participant was considered to have OSA if they answered "yes" to any one of the following three binary questions: (1) feeling overly drowsy during the day 16 to 30 times a month, even though they sleep for seven or more hours on workdays; (2) having trouble breathing, snoring, or gasping on three or more nights per week; (3) snoring on three or more evenings per week. This definition, first introduced in NHANES 2005–2008 data, has been validated and widely used in numerous epidemiological studies to explore associations between OSA and health outcomes.[20]

TyG Index Assessment

The TyG index and its associated indices were calculated using triglyceride (TG) and glucose levels (measured in mg/dl), waist circumference (WC) and height (measured in cm), and body mass index (BMI) (measured in kg/m²).[21]

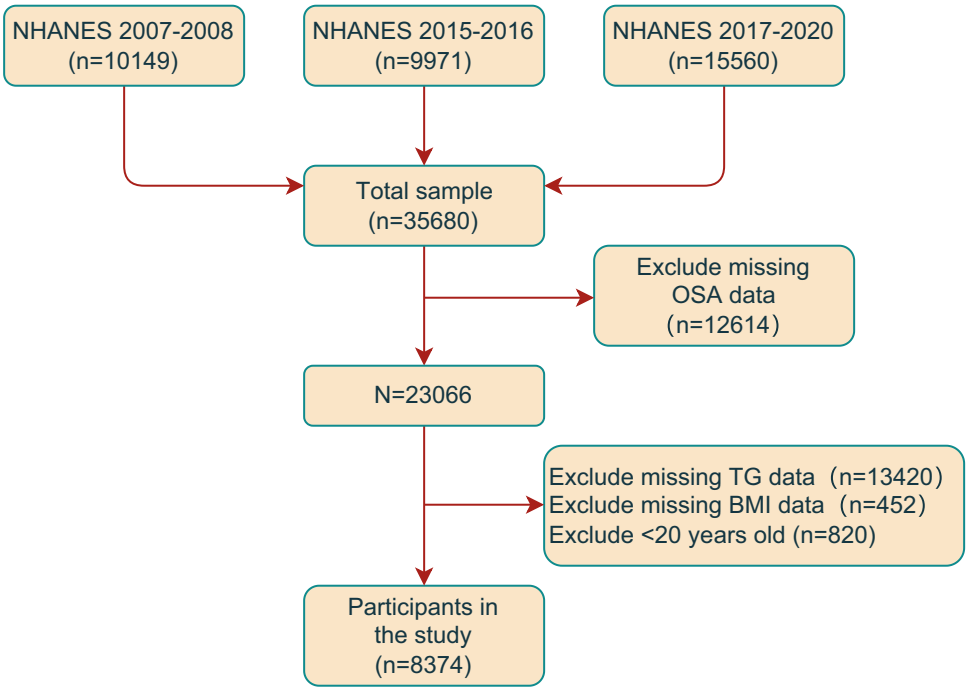

Figure 1 Flow chart showing the NHANES participants' selection.

WC, height, and weight were measured by trained health technicians at NHANES mobile exam centers. Height was recorded using a fixed stadiometer, with participants standing straight, heels together, and aligned with the Frankfort horizontal plane. Weight was measured using an electronic scale, with participants wearing only undergarments, a disposable paper gown, and foam slippers. WC was measured at the upper edge of the iliac crest using a flexible tape placed horizontally around the torso.

Fasting blood samples for TG and glucose levels were collected on-site by trained personnel. These samples were properly preserved and transported to certified laboratories for standardized analysis. This standardized process ensured the reliability of all measurements used to compute the TyG index and its derivatives.

$$\mathrm{TyG} = \ln\left[\frac{\mathrm{TG} \times \mathrm{glucose}}{2}\right]$$

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

$$\mathrm{TyG-WHtR} = \mathrm{TyG} \times \frac{\mathrm{WC}}{\mathrm{height}}$$

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

Covariate Assessment

This study included several covariates: education level, race, age, gender, marital status, and the poverty-to-income ratio (PIR) (<1.3 or ≥1.3). Smoking history was assessed by the question, "Have you ever smoked at least 100 cigarettes in your lifetime?" Alcohol consumption was assessed with the question, "Do you drink 4–5 or more drinks per day?[22]" Hypertension, diabetes, and dyslipidemia were determined by asking participants whether they had ever been diagnosed with these conditions by a physician or other healthcare provider. Physical activity (PA) levels were assessed using the Global Physical Activity Questionnaire (PAQ) from NHANES.[23,24] The questionnaire measured the frequency and duration of participants' vigorous and moderate-intensity physical activities per week. The total PA time was calculated

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using the formula: 2 * vigorous activity time + moderate activity time.[25] Based on WHO recommendations, participants were categorized into three groups based on total weekly activity time (≥150 minutes) and frequency (≥2 sessions per week):[24,26] (1) inactive: no vigorous or moderate-intensity PA; (2) insufficiently active: less than 150 minutes of total PA per week; (3) regularly active: at least 3 physical activities per week, with a total duration of at least 150 minutes.

When analyzing the relationship between TyG indices and OSA, we included TyG-BMI, TyG-WC, and TyG-WHtR as separate variables in the models. For TyG-BMI analysis, BMI was not included as a covariate because it is already incorporated into the TyG-BMI index. However, when analyzing TyG, TyG-WC, and TyG-WHtR, BMI was included as an important covariate to control for potential confounding factors more comprehensively.

Statistical Analysis

The normality of continuous variables was assessed using the Anderson-Darling test. Based on the results of this test, continuous variables such as age, BMI, TyG, TyG-BMI, TyG-WC, and TyG-WHtR were found to significantly deviate from normality. The Chi-square test was used to analyze categorical data and compare the characteristics of participants with and without OSA, while the Kruskal–Wallis *H*-test was applied for continuous variables. Participants were categorized into quartiles (Q1, Q2, Q3, and Q4) based on their TyG, TyG-BMI, TyG-WC, and TyG-WHtR values. The association between TyG-related markers and OSA was assessed using three multivariable logistic regression models. The strength of these associations was represented by odds ratios (OR) or adjusted odds ratios (AOR) with their corresponding 95% confidence intervals (CI). Model 1 included no covariates, Model 2 adjusted for income, marital status, age, race, education level and gender. For TyG-BMI, Model 3 further adjusted for diabetes, hypertension, hyperlipidemia, alcohol consumption, smoking history, and PA patterns. For TyG, TyG-WC, and TyG-WHtR, Model 3 additionally adjusted for BMI as an important covariate. Missing data were handled using multiple imputation to minimize bias and ensure robustness of the results. Subgroup analyses were conducted to examine potential variations across demographic characteristics such as gender, race, age, marital status, and income. Potential dose-response relationships between TyG-related indices and OSA were explored using restricted cubic splines (RCS). Receiver operating characteristic (ROC) curves were used to compare the predictive ability of the four indices, and the cutoff values along with their sensitivity and specificity were evaluated. P-values less than 0.05 were considered statistically significant. Statistical analysis was performed using R software (version 3.4).

Results

Baseline Characteristics

8374 people in all fulfilled the study requirements and were analyzed. Table 1 classifies the individuals baseline characteristics based on whether or not they have OSA. The OSA group consists of 4151 individuals. Of the participants, 51.18% were female and 48.82% were male. The median age for the total group was 51 years. 852.84 (735.29, 974.78), 244.31 (205.79, 290.48), 8.55 (8.10, 9.01), and 5.12 (4.41, 5.85) were the median values for TyG-WC, TyG-BMI, TyG,

Table 1 Baseline Characteristics of OSA in Adults Aged 20 years and Older

Variables	Total (n = 8374)	OSA		P
		No (n = 4223)	Yes (n = 4151)	
Age (years)	51.00 (36.00, 64.00)	48.00 (32.00, 64.00)	53.00 (39.00, 64.00)	<0.01
Fasting blood glucose (mg/dL)	103.00 (95.00, 114.00)	101.00 (94.00, 111.00)	105.00 (97.00, 117.00)	<0.01
BMI (kg/m²)	28.30 (24.59, 32.96)	26.81 (23.49, 31.12)	29.69 (26.10, 34.60)	<0.01
TyG	8.55 (8.10, 9.01)	8.45 (8.01, 8.91)	8.66 (8.22, 9.10)	<0.01
TyG-BMI	244.31 (205.79, 290.48)	228.83 (192.84, 270.75)	260.33 (222.40, 308.14)	<0.01
TyG-WC	852.84 (735.29, 974.78)	804.38 (692.00, 922.84)	894.53 (791.33, 1018.05)	<0.01
TyG-WHtR	5.12 (4.41, 5.85)	4.84 (4.15, 5.57)	5.35 (4.72, 6.08)	<0.01

(*Continued*)

Table 1 (Continued).

Variables	Total (n = 8374)	OSA		P
		No (n = 4223)	Yes (n = 4151)	
Gender (%)				<0.01
Male	4088 (48.82)	1858 (44.00)	2230 (53.72)	
Female	4286 (51.18)	2365 (56.00)	1921 (46.28)	
Education level (%)				<0.01
Less than high school graduate	1959 (23.39)	936 (22.16)	1023 (24.64)	
High school graduate or GED	1975 (23.58)	961 (22.76)	1014 (24.43)	
Some college or above	4440 (53.02)	2326 (55.08)	2114 (50.93)	
Race (%)				0.01
Mexican American	1273 (15.20)	599 (14.18)	674 (16.24)	
Non-Hispanic white	984 (11.75)	470 (11.13)	514 (12.38)	
Non-Hispanic black	3176 (37.93)	1642 (38.88)	1534 (36.95)	
Other Hispanic	1851 (22.10)	941 (22.28)	910 (21.92)	
Other race	1090 (13.02)	571 (13.52)	519 (12.50)	
Marital status (%)				0.17
Living alone	3404 (40.65)	1686 (39.92)	1718 (41.39)	
Married/Living with a partner	4970 (59.35)	2537 (60.08)	2433 (58.61)	
Income level (%)				0.49
Non-low income	5662 (67.61)	2870 (67.96)	2792 (67.26)	
Low income	2712 (32.39)	1353 (32.04)	1359 (32.74)	
Alcoholic ≥ 4 drinks/day (%)				0.82
Yes	1344 (16.05)	674 (15.96)	670 (16.14)	
No	7030 (83.95)	3549 (84.04)	3481 (83.86)	
Smoked ≥ 100 cigarettes in life (%)				0.24
Yes	3744 (44.71)	1915 (45.35)	1829 (44.06)	
No	4630 (55.29)	2308 (54.65)	2322 (55.94)	
Hypertension (%)				0.95
Yes	2761 (32.97)	1391 (32.94)	1370 (33.00)	
No	5613 (67.03)	2832 (67.06)	2781 (67.00)	
Hyperlipidemia (%)				0.46
Yes	3079 (36.77)	1569 (37.15)	1510 (36.38)	
No	5295 (63.23)	2654 (62.85)	2641 (63.62)	
Diabetes Mellitus (%)				0.34
Yes	1058 (12.63)	519 (12.29)	539 (12.98)	
No	7316 (87.37)	3704 (87.71)	3612 (87.02)	
Physical activity pattern (%)				0.47
Inactive	4488 (53.59)	2281 (54.01)	2207 (53.17)	
Insufficiently active	1235 (14.75)	631 (14.94)	604 (14.55)	
Regular active	2651 (31.66)	1311 (31.04)	1340 (32.28)	
TyG quantile (%)				<0.01
Q1	2090 (24.96)	1281 (30.33)	809 (19.49)	
Q2	2095 (25.02)	1098 (26.00)	997 (24.02)	
Q3	2095 (25.02)	979 (23.18)	1116 (26.89)	
Q4	2094 (25.01)	865 (20.48)	1229 (29.61)	
TyG-BMI quantile (%)				<0.01
Q1	2094 (25.01)	1413 (33.46)	681 (16.41)	
Q2	2093 (24.99)	1140 (27.00)	953 (22.96)	
Q3	2093 (24.99)	934 (22.12)	1159 (27.92)	
Q4	2094 (25.01)	736 (17.43)	1358 (32.72)	

(*Continued*)

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Table 1 (Continued).

Variables	Total (n = 8374)	OSA		P
		No (n = 4223)	Yes (n = 4151)	
TyG-WC quantile (%)				<0.01
Q1	2094 (25.01)	1443 (34.17)	651 (15.68)	
Q2	2093 (24.99)	1106 (26.19)	987 (23.78)	
Q3	2093 (24.99)	947 (22.42)	1146 (27.61)	
Q4	2094 (25.01)	727 (17.22)	1367 (32.93)	
TyG-WHtR quantile, n(%)				<0.01
Q1	2094 (25.01)	1428 (33.81)	666 (16.04)	
Q2	2093 (24.99)	1090 (25.81)	1003 (24.16)	
Q3	2093 (24.99)	939 (22.24)	1154 (27.80)	
Q4	2094 (25.01)	766 (18.14)	1328 (31.99)	

and TyG-WHtR. Mexican Americans and non-Hispanic whites made up a larger percentage of the OSA group than the non-OSA group. In terms of education, the proportion with higher education was slightly lower in the OSA group. Regarding lifestyle factors, there were no discernible variations between the two groups in smoking and drinking behavior, or PA levels. However, the OSA group had higher TyG, TyG-BMI, TyG-WC, and TyG-WHtR indices.

Association Between TyG-Related Indices and OSA

Three multivariable regression models were created to analyze the relationship between OSA and TyG-related indices in greater detail (Table 2). In the unadjusted Model 1, multivariable logistic regression analysis demonstrated a significant positive association between OSA and the TyG, TyG-BMI, TyG-WC, and TyG-WHtR indices. In Model 3, after covariate adjustment (with TyG, TyG-WC, and TyG-WHtR additionally adjusted for BMI compared to TyG-BMI), these significant associations persisted (TyG: AOR = 1.229, 95% CI: 1.145–1.319; TyG-BMI: AOR = 1.008, 95% CI: 1.007–1.008; TyG-WC: AOR = 1.016, 95% CI: 1.011–1.021 per 10 units; TyG-WHtR: AOR = 1.282, 95% CI: 1.174–1.400). Specifically, for each unit increase in TyG and TyG-WHtR, the risk of OSA increased by 22.9% and 28.2%, respectively, while for each 10-unit increase in TyG-WC, the risk increased by 1.6%.

Table 2 Association Between TyG, TyG-BMI, TyG-WC, TyG-WHtR and OSA

	Model 1	Model 2	Model 3
TyG			
Continuous	1.559 (1.462 ~ 1.661) <0.001	1.472 (1.376 ~ 1.575) < 0.001	1.229 (1.145 ~ 1.319) < 0.001
Categories			
Quartile 1	Reference	Reference	Reference
Quartile 2	1.438 (1.272 ~ 1.626) <0.001	1.355 (1.194 ~ 1.537) <0.001	1.172 (1.029 ~ 1.334) 0.017
Quartile 3	1.805 (1.596 ~ 2.041) <0.001	1.667 (1.466 ~ 1.895) <0.001	1.304 (1.141 ~ 1.490) < 0.001
Quartile 4	2.250 (1.988 ~ 2.546) <0.001	2.030 (1.779 ~ 2.315) <0.001	1.448 (1.260 ~ 1.663) < 0.001
P for trend	<0.001	<0.001	<0.001
TyG-BMI			
Continuous	1.008 (1.007 ~ 1.008) <0.001	1.008 (1.007 ~ 1.008) <0.001	1.008 (1.007 ~ 1.008) <0.001
Categories			
Quartile 1	Reference	Reference	Reference
Quartile 2	1.735 (1.530 ~ 1.967) <0.001	1.574 (1.385 ~ 1.790) <0.001	1.575 (1.385 ~ 1.791) <0.001
Quartile 3	2.575 (2.271 ~ 2.919) <0.001	2.403 (2.113 ~ 2.734) <0.001	2.402 (2.112 ~ 2.733) <0.001
Quartile 4	3.828 (3.368 ~ 4.352) <0.001	3.791 (3.325 ~ 4.323) <0.001	3.785 (3.319 ~ 4.317) <0.001
P for trend	<0.001	<0.001	<0.001

(*Continued*)

Table 2 (Continued).

	Model 1	Model 2	Model 3
TyG-WC			
Continuous (per 10 units)	1.030 (1.027 ~ 1.033)	1.028 (1.026 ~ 1.031) <0.001	1.016 (1.011 ~ 1.021) < 0.001
Categories			
Quartile 1	Reference	Reference	Reference
Quartile 2	1.978 (1.744 ~ 2.244) <0.001	1.852 (1.627 ~ 2.110) <0.001	1.503 (1.305 ~ 1.731) < 0.001
Quartile 3	2.682 (2.364 ~ 3.044) <0.001	2.494 (2.187 ~ 2.845) <0.001	1.749 (1.489 ~ 2.054) < 0.001
Quartile 4	4.168 (3.663 ~ 4.742) <0.001	3.910 (3.417 ~ 4.474) <0.001	2.089 (1.693 ~ 2.577) < 0.001
P for trend	<0.001	<0.001	<0.001
TyG-WHtR			
Continuous	1.586 (1.518 ~ 1.657) <0.001	1.608 (1.535 ~ 1.685) <0.001	1.282 (1.174 ~ 1.400) < 0.001
Categories			
Quartile 1	Reference	Reference	Reference
Quartile 2	1.973 (1.740 ~ 2.237) <0.001	1.899 (1.667 ~ 2.162) <0.001	1.503 (1.305 ~ 1.732) < 0.001
Quartile 3	2.635 (2.323 ~ 2.989) <0.001	2.569 (2.250 ~ 2.932) <0.001	1.735 (1.476 ~ 2.040) < 0.001
Quartile 4	3.717 (3.271 ~ 4.225) <0.001	3.839 (3.350 ~ 4.400) <0.001	1.913 (1.548 ~ 2.365) < 0.001
P for trend	<0.001	<0.001	<0.001

Notes: Model 1: There was no covariate adjustment.Model 2: Modified for income, marital status, age, race, education level and gender.Model 3: TyG-BMI further modified for PA patterns, smoking history, alcohol consumption, diabetes, hypertension, and hyperlipidemia. In addition to the factors mentioned above, adjust for BMI for TyG, TyG-WC, and TyG-WHtR.

Subsequently, these indices were transformed into quartile categories for sensitivity analysis. In Model 3, individuals in the highest quartile of TyG, TyG-BMI, TyG-WC, and TyG-WHtR exhibited significantly higher rates of OSA compared to those in the lowest quartile (TyG: AOR = 1.448, 95% CI: 1.260–1.663; TyG-BMI: AOR = 3.785, 95% CI: 3.319–4.317; TyG-WC: AOR = 2.089, 95% CI: 1.629–2.677; TyG-WHtR: AOR = 1.913, 95% CI: 1.548–2.363).

Subgroup Analysis

Subgroup analysis (Figure 2) showed significant interactions for TyG-WHtR in the age (p for interaction = 0.014) and income level (p for interaction = 0.003) subgroups. Specifically, TyG-WHtR had a stronger association with OSA in the 41–59 age group (AOR = 1.459, 95% CI: 1.254–1.698) and the low-income group (AOR = 1.451, 95% CI: 1.241–1.698). For other indices, the p values for interaction in subgroup analyses were all greater than 0.05, indicating no significant differences.

Dose-Response Relationship and Threshold Effect Analysis

Figure 3 shows the dose-response relationship between TyG, TyG-BMI, TyG-WC, TyG-WHtR, and OSA, while Supplementary Table 1 summarizes their threshold effect analysis. TyG has a linear relationship with OSA, whereas TyG-BMI, TyG-WC, and TyG-WHtR exhibit nonlinear relationships. Supplementary Table 1 presents TyG-BMI has an inflection point at 317.063, with slopes of 1.010 and 1.002 below and above this point; TyG-WC has an inflection point at 1044.906, with slopes of 1.002 and 0.999; TyG-WHtR has an inflection point at 5.723, with slopes of 1.475 and 0.981. The log-likelihood ratio test results were all significant ($P < 0.001$).

Assessment of TyG-Related Indices in Diagnosing OSA

The diagnostic performance of TyG, TyG-BMI, TyG-WC, and TyG-WHtR for OSA is shown in Supplementary Table 2 and Figure 4. The most effective diagnostic method was TyG-WC, with an AUC of 0.647 (95% CI: 0.636–0.659). Closely behind, with an AUC of 0.644 (95% CI: 0.632–0.656), was TyG-BMI. However, TyG's diagnostic capacity was comparatively weaker, as evidenced by its AUC of 0.588 (95% CI: 0.576–0.600). The ideal cutoff points for TyG-BMI, TyG-WC, and TyG-WHtR were determined to be 241.190, 814.252, and 4.804, respectively, based on the criteria shown in the table Sensitivities of 0.631, 0.699, and 0.723 and specificities of 0.585, 0.524, and 0.486 were obtained using these cutoffs. These results highlight the TyG-related indices' potential clinical value in determining OSA risk.

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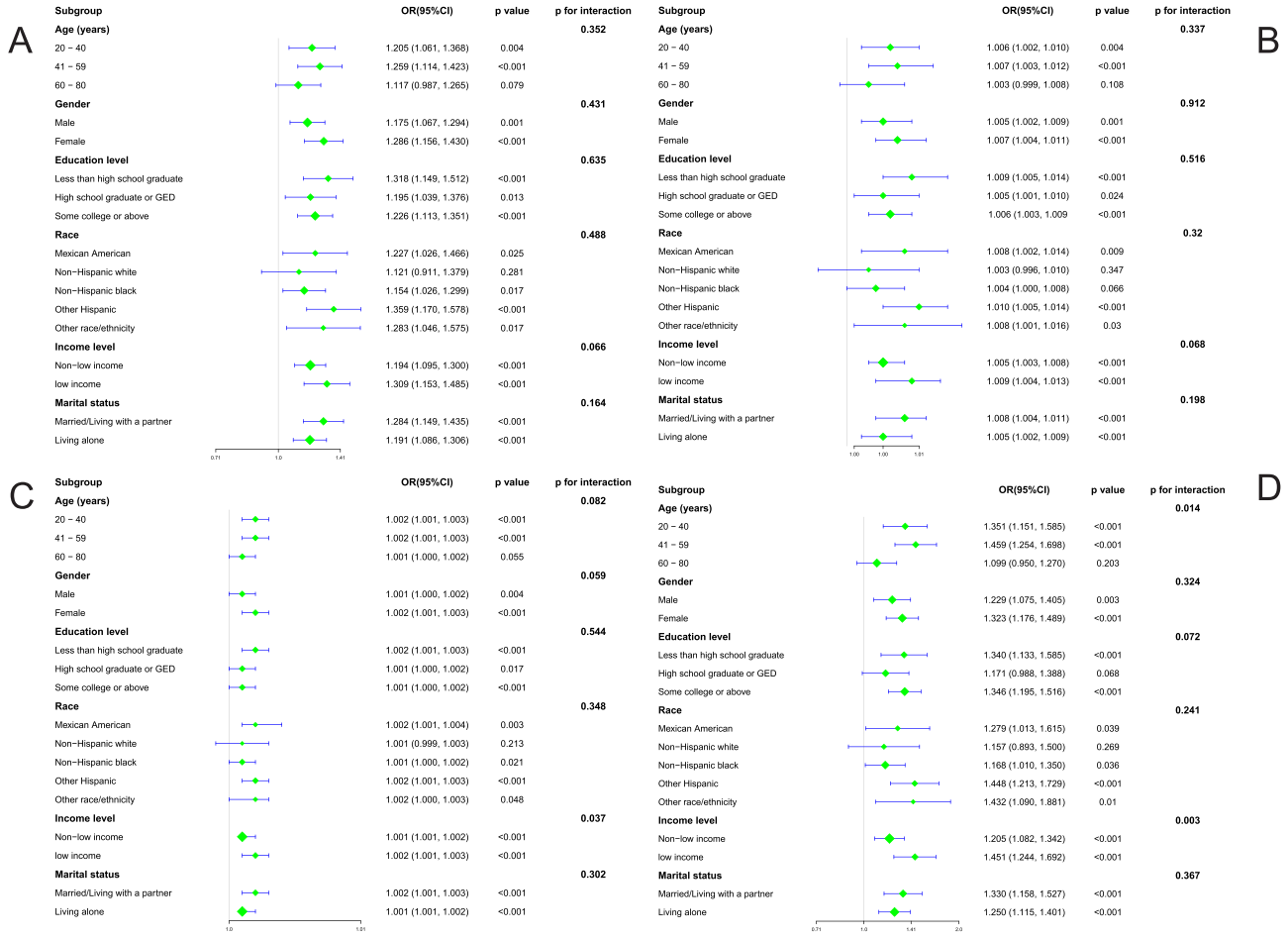

Figure 2 Subgroup Analysis of TyG, TyG-BMI, TyG-WC, and TyG-WHtR with OSA **(A)** Subgroup analysis results of TyG index (**A**) with OSA. **(B)** Subgroup analysis results of TyG-BMI index (**B**) with OSA. **(C)** Subgroup analysis results of TyG-WC index (**C**) with OSA. **(D)** Subgroup analysis results of TyG-WHtR index (**D**) with OSA.

Discussion

In this study, we systematically evaluated the effectiveness of metabolic indices such as TyG, TyG-BMI, TyG-WC, and TyG-WHtR in diagnosing OSA. We discovered a substantial positive connection between these indices and OSA after correcting for all pertinent factors. Among them, TyG-WC and TyG-BMI demonstrated superior diagnostic performance, with AUC of 0.647 and 0.644, respectively, indicating that TyG-WC has the best predictive ability. Additionally, we explored the dose-response relationships and threshold effects between these indices and the risk of OSA, finding significant changes in the slopes of TyG-BMI, TyG-WC, and TyG-WHtR beyond specific inflection points. Subgroup analysis further revealed that TyG-WHtR is more strongly associated with OSA in middle-aged and low-income groups, with no significant differences observed in other subgroups.

OSA is a prevalent sleep condition that causes hypoxia and raises the risk of illnesses of the heart and brain,[27] hypertension,[28] and dementia.[29] Additionally, it is a significant independent predictor of all-cause mortality and cardiovascular illnesses.[30–33] Research indicates that IR is a key linking mechanism between OSA and its related diseases. Consequently, the scientific community seeks effective methods for measuring IR, among which the TyG index, due to its simplicity and cost-effectiveness, has been proven to be an effective alternative to the HOMA-IR and the HEC.[34]

Studies from Korea and Hungary have shown that elevated TyG indices significantly increase the risk of OSA, regardless of whether the patients are obese or diabetic.[35,36] Our research focuses on TyG-related indices, including TyG-WC, TyG-BMI, and TyG-WHtR. TyG-WC incorporates waist circumference, reflecting the distribution of abdominal fat; TyG-BMI integrates the BMI to assess the relationship between overall obesity and metabolic status; and TyG-WHtR

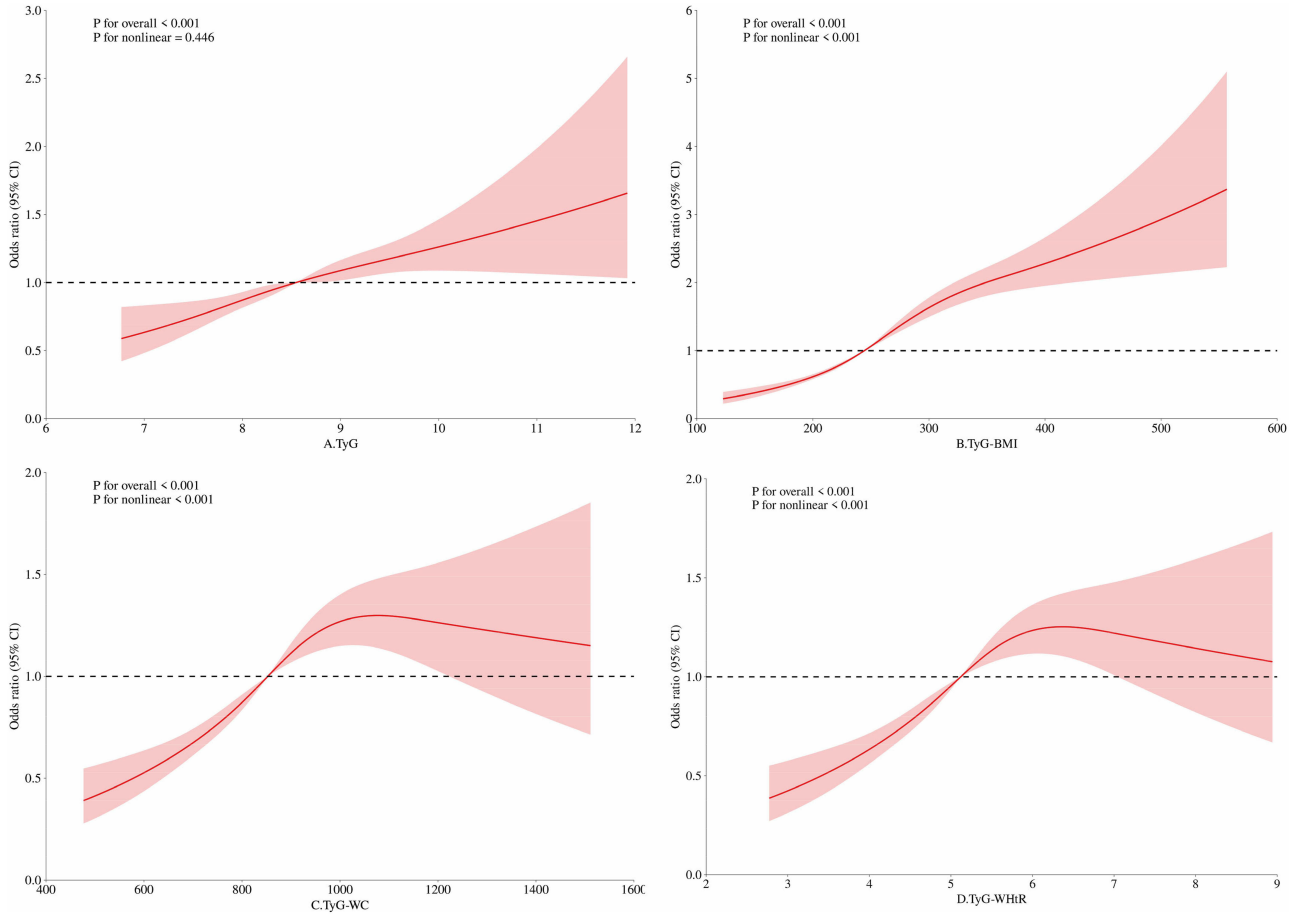

Figure 3 Dose-Response Relationship between TyG, TyG-BMI, TyG-WC, TyG-WHtR and OSA P for overall indicates the statistical significance of the overall relationship, P for nonlinear indicates the statistical significance of the nonlinear relationship. All covariates have been adjusted.

further includes height factors, offering a more refined assessment of abdominal obesity.[11] Studies have indicated that a major risk factor for OSA is abdominal obesity, affecting respiratory muscle function, increasing upper airway resistance, and potentially altering airway structure and function.[37,38] Additionally, NHANES research has confirmed that elevated levels of Lipid Accumulation Product (LAP) and Visceral Adiposity Index (VAI) are associated with an increased risk of OSA.[39] According to two Chinese research that predicted OSA patients' prognosis using modified TyG indices, higher TyG-WC is positively connected with myocardial infarction risk[40] and is useful in predicting non-alcoholic fatty liver disease risk in OSA cases.[41,42] Moreover, the latest NHANES data also indicate that elevated TyG indices are closely associated with OSA and can independently predict the risk of OSA.[15] These results are in line with what our study found. Compared to the original study, our research introduces multiple TyG-derived indices, allowing for a more comprehensive and precise assessment of OSA risk, particularly in terms of the impact of abdominal fat on upper airway resistance. Additionally, we employed a more thorough control of covariates, including factors like physical activity,[43] minimizing potential biases. To avoid the sample size reduction caused by traditional exclusion methods, we used multiple imputation techniques to handle missing data, further enhancing the robustness and reliability of our findings.

Existing research has extensively explored the link and underlying mechanisms between IR, abdominal obesity, and OSA. Studies indicate that OSA, by increasing nocturnal hypoxia and frequent awakenings, activates the sympathetic nervous system, thereby inducing IR and hyperinsulinemia.[44,45] IR is closely associated with an increase in visceral fat, not just with obesity.[46] Visceral fat is prone to causing IR and inflammatory responses, secreting significant levels of pro-inflammatory cytokines such as IL-6 and TNF-α, which are particularly pronounced in patients with OSA.[47] Additionally,

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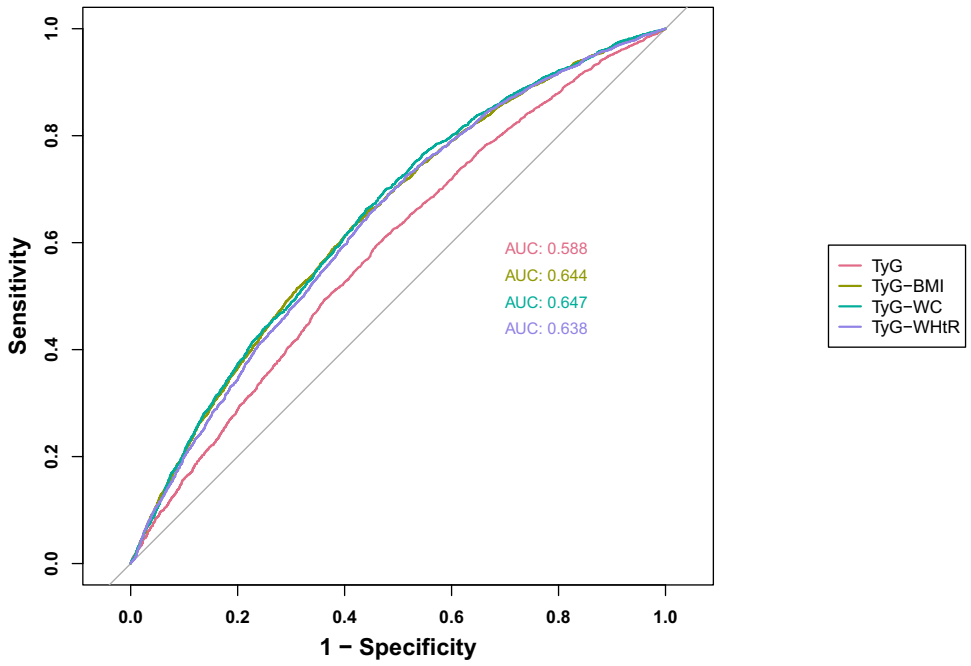

Figure 4 ROC Curve Analysis of TyG, TyG-BMI, TyG-WC, and TyG-WHtR in Diagnosing OSA.

OSA leads to sleep deprivation and fragmentation, disrupting metabolic processes, increasing appetite, and altering metabolic rhythms, thus exacerbating obesity and IR.[48,49] This metabolic disruption not only affects short-term health but may also lead to long-term metabolic disorders, aggravating OSA symptoms.[44] In patients with high visceral fat, hypoxic stress caused by OSA interferes with glucose metabolism through leptin resistance and increased inflammation, which further exacerbates OSA symptoms. This creates a vicious cycle in which OSA leads to insulin resistance, and insulin resistance, in turn, aggravates visceral fat accumulation and OSA symptoms, promoting a continuous worsening of both conditions.[50,51]

The subgroup analysis indicates that TyG-WHtR shows a stronger association with OSA in the 41–59 age group and in the low-income group. These results highlight the effectiveness of TyG-WHtR as a tool for assessing OSA risk, especially in middle-aged populations with a high prevalence of metabolic syndrome and obesity-related diseases. The middle-aged stage is often associated with increased metabolic disturbances and obesity, which in turn raises the risk of developing OSA.[52] Low-income groups, due to higher levels of stress, poorer dietary habits, and lifestyle factors, face an increased risk of metabolic syndrome and obesity, leading to a higher prevalence of OSA.[53] Therefore, the application of TyG-WHtR in these high-risk populations, particularly in middle-aged and low-income groups, can serve as an important screening tool to identify and intervene early in high-risk individuals, ultimately improving overall health and reducing the incidence of OSA.

The limitations of this study include: Firstly, due to the cross-sectional design, it is not possible to determine the causal relationship between TyG-related indices and OSA. Future studies should employ longitudinal research or randomized controlled trials to explore the causal relationships between these indices and OSA risk. Secondly, the diagnosis of OSA relies on self-reporting rather than objective methods like polysomnography, which may lead to underestimation or misclassification of disease prevalence, affecting the accuracy of results. Additionally, although various covariates were adjusted, potential confounders such as family history and environmental factors were not included, which may affect the accuracy and generalizability of the results. Future research should consider a more comprehensive analysis that includes more confounding factors.

The measurement of TyG and its related indices is simple, requiring no expensive equipment, just routine blood tests and basic physical assessments, making it particularly suitable for resource-limited settings such as community clinics and rural medical facilities. The high applicability and low cost of the TyG index make it an ideal assessment tool. In

clinics, by entering patient data into a TyG calculator, doctors can quickly obtain an OSA risk assessment, providing immediate results. This not only helps doctors make rapid initial assessments but also determines the need for further sleep monitoring or other diagnostic measures, significantly enhancing the efficiency and effectiveness of OSA management. Future research should further validate the applicability of these indices across different populations, explore how to integrate these simple assessment tools into existing clinical pathways, and assess their potential application in various global healthcare settings.

Conclusion

The results of our study demonstrate a strong association between TyG and its correlated indices (TyG-BMI, TyG-WC, TyG-WHtR) and OSA, with TyG-WC being especially useful in predicting OSA risk. Based on these findings, we highlight the potential of TyG and related indices as promising tools for early diagnosis of OSA, particularly in settings with limited access to advanced diagnostic resources. Future research, particularly long-term studies, is needed to explore the causal relationships between these markers and OSA to improve management strategies in these settings.

Data Sharing Statement

The data used in this study came from the NHANES, which the general public can access through Centers for Disease Control and Prevention website. Both the general public and researchers can access the NHANES datasets without charge.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Consent to Participate

Not relevant. The National Health and Nutrition Examination Survey (NHANES) provided the data utilized in this investigation, and the original data collectors acquired informed consent before using the data.

Consent to Publish Statement

All authors of this manuscript have read the final version and consent to its content. All authors agree to its publication in the journal accepting the manuscript.

Human Ethics and Consent to Participate

This study uses anonymized data from publicly available databases, and all data are used in a manner that does not involve human trials or have a direct impact on the participants. According to Article 32, Items 1 and 2 of the "Ethical Review Measures for Life Science and Medical Research Involving Humans" (released on February 18, 2023) in China, this study meets the criteria for exemption from ethical review. Therefore, this study does not require approval from an ethics review committee, nor is informed consent from participants necessary.

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Disclosure

In this study, both XF and ZYT declare no conflicts of interest.

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