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The Association between TyG-WHtR Index and Obstructive Sleep Apnea Risk in American Adults: A Nationwide Cross-Sectional Study

Faguang Luo[1,2], Rong Xie[1*]

[1]People's Hospital of Yangjiang (Affiliated Yangjiang Hospital of Guangdong Medical University), Yangjiang, China
[2]Guangdong Cardiovascular Institute, Guangdong Provincial People's Hospital, Guangdong Academy of Medical Sciences, Guangzhou, China
Email: *rongxie9909@163.com

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Abstract

Background: Obstructive sleep apnea (OSA) is a common sleep disorder in the population, which is closely related to cardiovascular diseases and metabolic diseases. Traditional obesity indicators such as body mass index (BMI) and waist circumference (WC) have obvious limitations in assessing OSA risk, mainly because they cannot accurately reflect the actual distribution of fat and related metabolic abnormalities. The triglyceride-glucose-waist-to-height ratio (TyG-WHtR) integrates metabolic indicators with anthropometric indicators, which may provide a more accurate tool for OSA risk assessment. The main purpose of this study is to look at the relationship between TyG-WHtR and OSA risk in the adult population, and to evaluate whether it can play a role as a screening tool in clinical practice. **Methods:** A total of 3193 participants in the National Health and Nutrition Examination Survey (NHANES) from 2017 to 2020 were included in this cross-sectional study. We use a multivariate logistic regression model. On the one hand, TyG-WHtR is treated as a continuous variable, and on the other hand, it is treated as a categorical variable to evaluate its relationship with OSA risk. In order to further verify the robustness of the results, we also performed subgroup analysis, dose-response relationship analysis, threshold effect analysis, and sensitivity analysis. **Results:** Among the 3193 participants included in the study, there was a significant correlation between higher TyG-WHtR and higher self-reported OSA risk. After adjusting for potential confounding factors, the odds ratio (OR) between TyG-WHtR and self-reported OSA risk reached 1.59 (95 % CI: 1.47-1.72). Dose-response analysis showed that with the increasing level of TyG-WHtR, the risk of self-reported OSA was also increasing. Further analysis also found that there is a threshold effect between TyG-WHtR and self-reported

OSA risk, and the inflection point falls at the position of 5.26. That is to say, on both sides of this critical value, the increase in OSA risk will be different. The results of sensitivity analysis further support the stability of the above correlation. **Conclusion:** TyG-WHtR can be used as a useful marker of self-reported OSA risk, and may also be a relatively convenient screening tool, especially in resource-limited areas where polysomnography is still difficult to popularize. However, some prospective studies are still needed in the future, so as to better verify our current results and further clarify the biological mechanism behind this association.

Keywords

TyG-WHtR, Obstructive Sleep Apnea, Cross-Sectional Study, NHANES, Metabolic Risk

1. Introduction

OSA is a relatively common sleep-related respiratory disorder. Its main feature is that the upper airway will be blocked repeatedly during sleep. This obstruction can lead to intermittent hypoxia, sleep interruption, and significant fluctuations in intrathoracic pressure [1]. Many OSA patients usually show loud snoring, and they often wake up repeatedly because of wheezing or suffocation during sleep, and often feel particularly sleepy during the day. If the condition is more serious, the patient's cognitive function will sometimes be affected, and there may be some changes in behavior [2]. At present, OSA has become an important public health burden worldwide. It is estimated that among adults aged 30 - 69 years, about 936 million people are affected by OSA, of which about 425 million are moderate to severe patients [3]. The prevalence of OSA has been increasing worldwide, which is closely related to the increasing prevalence of obesity, the accelerated aging of the population, and the extensive changes in people's lifestyles [4].

If OSA has not been treated in time, it is possible to push up the risk of a variety of serious health problems, such as hypertension, cardiovascular disease, stroke, diabetes, and metabolic syndrome [5]-[8]. Part of these complications may be due to repeated hypoxia and sleep interruption, which leads to oxidative stress, systemic inflammation, and activation of the sympathetic nervous system. Over time, these pathophysiological changes will slowly promote the occurrence and progression of cardiac metabolic diseases [9]. On the other hand, there may be a two-way effect between OSA and metabolic dysfunction, especially the relationship between OSA and obesity. It is this close link that reminds us of the need to find some practical and relatively accurate biomarkers, so as to identify the high-risk population of OSA earlier [10].

Obesity is one of the major risk factors for OSA, especially when fat accumulates around the abdomen and internal organs. If central fat accumulates too much, it is possible to reduce the lumen diameter of the upper airway and make

it more prone to collapse during sleep, making breathing less [11] [12]. Because BMI and WC are easy to measure and obtain, they are often used to assess the OSA risk associated with obesity. However, neither of these two indicators can accurately distinguish visceral fat from subcutaneous fat. For the related metabolic abnormalities caused by fat distribution, the information they can reflect is actually limited [13].

In order to make up for those limitations mentioned above, many researchers have proposed several indices that combine metabolic indicators with anthropometric indicators. The triglyceride-glucose (TyG) index is often used as a relatively simple alternative indicator for assessing insulin resistance. This TyG index can be combined with waist-to-height ratio or BMI to further construct composite indices such as TyG-WHtR and TyG-BMI. Compared with the traditional obesity evaluation index, these composite indices may provide more information related to individual metabolic risk [14]-[16]. Previous studies have also found that the TyG-related index is closely related to insulin resistance, metabolic syndrome, and cardiovascular disease, suggesting that it may still be valuable in assessing OSA risk [17] [18].

There is a close relationship between OSA and metabolic dysfunction. In fact, there are many common potential mechanisms, such as insulin resistance and chronic inflammation. These pathological processes may promote each other and accelerate the progression of the two diseases together [12] [19]. It is this connection that makes us think that indexes such as TyG-WHtR, which can reflect both metabolic status and physical measurement information, may help to identify high-risk groups of OSA. However, at present, there are few studies on the relationship between TyG-WHtR and OSA. Therefore, this study used the nationally representative large-scale NHANES survey data to analyze the association between TyG-WHtR and self-reported OSA risk, and also wanted to see whether TyG-WHtR can be used as a more practical indicator to identify those who may need further assessment.

2. Methods

2.1. Study Population and Research Design

This study used data from the NHANES, which is conducted by the National Center for Health Statistics (NCHS) and is designed to represent the civilian, noninstitutionalized population of the United States. NHANES uses a multistage, stratified probability sampling design to collect information on the health and nutritional status of the U.S. population. The survey protocol was approved by the NCHS Research Ethics Review Board, and written informed consent was obtained from all participants. Data were collected through household interviews, physical examinations, and laboratory testing. Further information about NHANES is available on its official website(http://www.cdc.gov/nhanes).

This study included data collected during 2017-2020. During this period, participants will go to the NHANES mobile examination centers (MEC) for anthro-

pometric and laboratory testing. All inspections are completed in accordance with the standardized process, so as to ensure that the relevant measurement indicators of each participant are collected consistently during the same period of time during their participation in the survey.

Initially, 15,560 participants were enrolled in NHANES during the 2017-2020 cycles. After applying stringent inclusion and exclusion criteria, a final cohort of 3193 participants was identified as eligible for this study. Exclusion criteria were applied as follows: participants were excluded if they lacked complete data on the TyG index (n = 11,120), had missing data on OSA status (n = 731), were under 20 years of age (n = 329), or had incomplete covariate information (n = 187) (**Figure 1**).

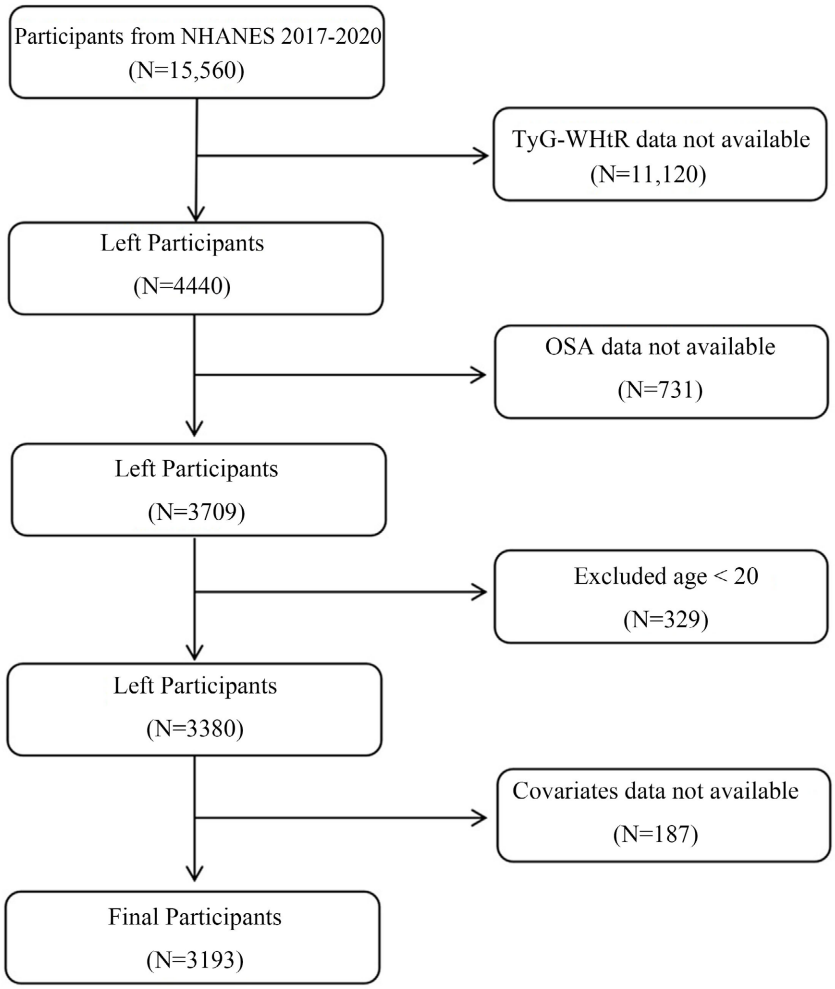

Figure 1. Flow chart of patient screening.

2.2. Definitions of the Exposure and Outcome Variables

The TyG-WHtR index was calculated using the following formula [8] [20]:

TyG = Ln[fasting triglycerides (mg/dL) × fasting blood glucose (mg/dL)/2].

WHtR = waist circumference/height.

TyG-WHtR = TyG index × WHtR.

OSA status was determined based on self-reported questionnaire data regarding participants' sleep habits and disorders, consistent with definitions used in prior research. Participants were classified as having OSA if they responded affirmatively to at least one of the following questions [21] [22]:

1) snoring three or more times per week;

2) experiencing episodes of gasping, snorting, or stopping their breath on three or more occasions per week;

3) being excessively or overly sleepy during the day 16 - 30 times per month, despite sleeping seven or more hours per night.

2.3. Measurement of Covariates

Information on demographic and lifestyle factors was obtained from participant questionnaires. The covariates included age, sex, race and ethnicity, education, marital status, smoking, and alcohol use. Race and ethnicity were grouped as Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, and other racial or ethnic groups. Marital status was divided into married or living with a partner and living alone. Education was categorized as less than high school, high school, or more than high school. Smoking status was defined according to whether participants had smoked at least 100 cigarettes during their lifetime. Alcohol use was treated as a binary variable based on whether participants reported ever consuming an alcoholic beverage. Information on hypertension, diabetes, and cardiovascular disease was based on self-reported physician diagnoses. Participants were considered to have hypertension or diabetes if they reported that a doctor or other health professional had told them they had the condition. Cardiovascular disease (CVD) was defined as a self-reported history of congestive heart failure, coronary heart disease, angina, myocardial infarction, or stroke. Participants who answered "yes" to any of these cardiovascular conditions were classified as having CVD.

2.4. Statistical Analysis

Baseline characteristics were summarized using descriptive statistics. Continuous variables are reported as means with standard deviations (SDs), whereas categorical variables are presented as numbers and percentages. Differences between participants with and without OSA were compared using independent-samples t-tests for continuous variables and chi-square tests for categorical variables. Multivariable logistic regression was used to examine the association between the triglyceride-glucose waist-to-height ratio (TyG-WHtR) and OSA. A total of three models were constructed. There is no adjustment for any covariates in model I; model II adjusted age, gender, race and ethnicity, education level and marital status. On the basis of Model II, Model III further added smoking, drinking, hypertension, cardiovascular disease and diabetes. In addition, we also divided TyG-WHtR into several groups according to the quartile to see whether there is a dose-

response relationship between it and OSA. In the fully adjusted model, the OSA odds ratios corresponding to different TyG-WHtR quartile arrays were estimated, and the lowest quartile array was used as a reference group to compare. Next, the threshold effect analysis is made, mainly to explore whether there may be a non-linear relationship, and to find out the potential inflection point. For TyG-WHtR below and above this threshold, the corresponding effect estimates are calculated respectively. Subgroup analyses were conducted according to sex, age, race and ethnicity, education, smoking, alcohol use, hypertension, diabetes, and cardiovascular disease. Potential differences between subgroups were evaluated using interaction tests. In order to further reduce the differences in baseline characteristics between the OSA group and the non-OSA group, we also used propensity score matching as a supplementary analysis. Propensity scores were estimated by logistic regression, and a 1:1 match was made. After the completion of the matching, the association between TyG-WHtR and OSA was reassessed in a new sample. In order to test whether the results of the study are stable or not, we excluded participants who were using hypoglycemic drugs or lipid-lowering drugs and then analyzed them again. Multicollinearity was assessed using variance inflation factors, and all included covariates had a VIF below 5. All statistical analyses were performed using R software (version 4.4.1) and EmpowerStats (version 4.2), with a P-value of <0.05 considered statistically significant.

3. Results

The study comprised a total of 3193 participants, categorized into 1574 non-OSA individuals and 1619 OSA cases, as detailed in Table 1. The average age of the cohort was 47.39 years, with a nearly equal gender distribution: 50.54% females and 49.46% males. The majority of participants identified as Non-Hispanic White. Comparative analysis revealed that the OSA group had significantly higher values for BMI, WC, WHtR, Fasting Blood Glucose (FBG), Triglycerides (TG), and the TyG-WHtR index compared to the non-OSA group. Furthermore, statistically significant differences were observed between the two groups regarding age, gender, marital status, education level, smoking history, and the prevalence of hypertension and diabetes ($P < 0.05$).

Multiple logistic regression models (Table 2) showed that each one-unit increase in TyG-WHtR was associated with a 63% increased of self-reported OSA in the unadjusted model (OR = 1.63, 95% CI: 1.52, 1.75), remaining robust after partial (Model II: OR = 1.61, 95% CI: 1.50, 1.74) and full adjustment for covariates (Model III: OR = 1.59, 95% CI: 1.47, 1.72). Sensitivity analysis by TyG-WHtR quartiles in Model III revealed a dose-response relationship, with odds ratios of 1.82 (95% CI: 1.47, 2.25), 2.70 (95% CI: 2.17, 3.36), and 3.67 (95% CI: 2.91, 4.62) for the second, third, and fourth quartiles, respectively, compared to the lowest quartile (P for trend < 0.0001). Threshold effect analysis identified an inflection point at TyG-WHtR = 5.26 (Table 3), with a 99% increased below this threshold (OR = 1.99, 95% CI: 1.72, 2.31) and a 30% increase above it (OR = 1.30, 95% CI:

1.14, 1.49), as depicted in Figure 2. Subgroup analyses confirmed consistent associations between TyG-WHtR and OSA across most subgroups, with stronger effects observed among individuals living alone (OR = 1.70, 95% CI: 1.50, 1.92) compared to those married or cohabiting, non-drinkers (OR = 2.45, 95% CI: 1.73, 3.49) compared to drinkers, and those aged ≤ 60 years (OR = 1.72, 95% CI: 1.57, 1.89) compared to those > 60 years (Table 4). Variance inflation factors for all adjusted covariates (Table S1) ensured covariates with VIF < 5 were included in the models, satisfying multicollinearity requirements.

Table 1. Baseline characteristics of participants in the NHANES 2017-2020.

Characteristics	Overall (n = 3193)	Non-OSA (n = 1574)	OSA (n = 1619)	P-value
Age (years)	47.39 (45.97, 48.82)	44.89 (43.47, 46.32)	50.08 (48.23, 51.94)	<0.0001
BMI (kg/m^2)	29.58 (29.14, 30.01)	27.85 (27.32, 28.39)	31.44 (31.03, 31.84)	<0.0001
WC (cm)	100.24 (99.12, 101.37)	95.60 (94.40, 96.79)	105.25 (103.93, 106.57)	<0.0001
Height (cm)	168.40 (167.97, 168.83)	168.00 (167.37, 168.64)	168.83 (168.06, 169.60)	0.1575
WHtR	0.60 (0.59, 0.60)	0.57 (0.56, 0.58)	0.62 (0.62, 0.63)	<0.0001
FBG (mg/dl)	109.11 (107.07, 111.16)	104.87 (103.17, 106.57)	113.69 (110.83, 116.54)	<0.0001
TG (mg/dl)	111.90 (106.46, 117.34)	101.34 (95.61, 107.07)	123.28 (117.06, 129.50)	<0.0001
TyG-WHtR	5.10 (5.02, 5.17)	4.80 (4.73, 4.88)	5.41 (5.34, 5.49)	<0.0001
Gender (%)				0.0121
Male	49.46 (46.46, 52.47)	45.44 (40.32, 50.65)	53.80 (50.06, 57.51)	
Female	50.54 (47.53, 53.54)	54.56 (49.35, 59.68)	46.20 (42.49, 49.94)	
Race (%)				0.4737
Mexican American	9.14 (6.64, 12.45)	8.62 (5.87, 12.48)	9.70 (7.18, 12.98)	
Other Hispanic	6.56 (5.19, 8.26)	5.99 (4.49, 7.96)	7.17 (5.53, 9.24)	
Non-Hispanic White	63.92 (59.62, 68.02)	65.17 (60.81, 69.30)	62.58 (56.90, 67.92)	
Non-Hispanic Black	10.53 (8.00, 13.73)	9.97 (7.81, 12.64)	11.13 (7.77, 15.69)	
Other Races	9.85 (7.71, 12.50)	10.24 (7.71, 13.47)	9.43 (7.08, 12.44)	
Education level (%)				<0.0001
Less than high school	10.24 (8.91, 11.73)	8.25 (6.79, 10.00)	12.38 (10.36, 14.72)	
High school	25.90 (23.15, 28.86)	22.81 (19.36, 26.68)	29.23 (25.88, 32.82)	
More than high school	63.86 (60.26, 67.31)	68.93 (64.35, 73.17)	58.40 (54.35, 62.33)	
Marital status (%)				0.0001
Married/Living with a partner	64.22 (58.86, 69.24)	59.46 (52.93, 65.66)	69.34 (64.36, 73.91)	
Living alone	35.78 (30.76, 41.14)	40.54 (34.34, 47.07)	30.66 (26.09, 35.64)	
Smoking status (%)				0.0001
Yes	42.79 (40.23, 45.40)	36.83 (32.69, 41.17)	49.22 (45.26, 53.19)	
No	57.21 (54.60, 59.77)	63.17 (58.83, 67.31)	50.78 (46.81, 54.74)	
Alcohol drinking (%)				0.1017
Yes	93.72 (91.99, 95.09)	92.65 (90.93, 94.06)	94.87 (91.92, 96.78)	
No	6.28 (4.91, 8.01)	7.35 (5.94, 9.07)	5.13 (3.22, 8.08)	

Continued

Hypertension (%)				<0.0001
Yes	30.99 (27.63, 34.58)	24.98 (22.62, 27.51)	37.48 (32.31, 42.95)	
No	69.01 (65.42, 72.37)	75.02 (72.49, 77.38)	62.52 (57.05, 67.69)	
CVD (%)				0.2356
Yes	8.35 (6.43, 10.77)	7.49 (5.42, 10.28)	9.27 (6.75, 12.59)	
No	91.65 (89.23, 93.57)	92.51 (89.72, 94.58)	90.73 (87.41, 93.25)	
Diabetes (%)				0.0001
Yes	10.48 (8.68, 12.59)	7.97 (6.53, 9.71)	13.17 (10.59, 16.28)	
No	87.67 (85.44, 89.60)	90.35 (88.07, 92.23)	84.78 (81.97, 87.22)	
Borderline	1.85 (1.30, 2.63)	1.68 (0.98, 2.85)	2.05 (1.31, 3.18)	

OSA, obstructive sleep apnea; BMI, body mass index; WC, waist circumference; TG, triglycerides; TyG-WHtR, triglyceride-glucose-waist to height ratio; FBG, Fasting blood glucose; CVD, cardiovascular disease.

Table 2. Association between TyG-WHtR index and the risk of OSA.

Exposure	Model I	Model II	Model III
TyG-WHtR	1.63 (1.52, 1.75) <0.0001	1.61 (1.50, 1.74) <0.0001	1.59 (1.47, 1.72) <0.0001
TyG-WHtR index quartile			
Q1	Reference	Reference	Reference
Q2	2.05 (1.67, 2.52) <0.0001	1.84 (1.49, 2.28) <0.0001	1.82 (1.47, 2.25) <0.0001
Q3	3.06 (2.49, 3.76) <0.0001	2.77 (2.24, 3.44) <0.0001	2.70 (2.17, 3.36) <0.0001
Q4	4.04 (3.28, 4.98) <0.0001	3.88 (3.11, 4.84) <0.0001	3.67 (2.91, 4.62) <0.0001
P for trend	<0.0001	<0.0001	<0.0001

OSA, obstructive sleep apnea; TyG-WHtR, triglyceride-glucose-waist to height ratio. Model I model adjusted for: unadjusted; Model II model adjusted for: age; gender; race; education level; marital status; Model III model adjusted for: age; gender; race; education level; marital status; Smoking status; alcohol drinking; hypertension; CVD; diabetes.

Table 3. Analysis of the threshold effect between TyG-WHtR index and the risk of OSA.

Threshold effect analysis	OSA OR (95% CI) P-value
TyG-WHtR	
Inflection point of TyG-WHtR (K)	5.26
<K slope	1.99 (1.72, 2.31) <0.0001
>K slope	1.30 (1.14, 1.49) 0.0002
Log-likelihood ratio test	<0.001

Table 4. Subgroup analysis of the association between TyG-WHtR index and OSA.

Subgroup	OR (95% CI)	P for interaction
Gender		0.531
Male	1.60 (1.41, 1.81) <0.0001	
Female	1.55 (1.40, 1.72) <0.0001	

Continued

Age		0.0006
<=60	1.72 (1.57, 1.89) <0.0001	
>60	1.31 (1.12, 1.52) 0.0006	
Race		0.1298
Mexican American	1.66 (1.32, 2.10) <0.0001	
Other Hispanic	1.35 (1.02, 1.77) 0.0339	
Non-Hispanic White	1.53 (1.34, 1.74) <0.0001	
Non-Hispanic Black	1.72 (1.47, 2.01) <0.0001	
Other Races	1.80 (1.44, 2.24) <0.0001	
Education level		0.7317
Less than high school	1.55 (1.26, 1.91) <0.0001	
High school	1.48 (1.27, 1.73) <0.0001	
More than high school	1.67 (1.50, 1.85) <0.0001	
Marital status		0.0335
Married/Living with a partner	1.50 (1.35, 1.67) <0.0001	
Living alone	1.70 (1.50, 1.92) <0.0001	
Alcohol drinking		0.0201
Yes	1.57 (1.45, 1.70) <0.0001	
No	2.45 (1.73, 3.49) <0.0001	
Smoking status		0.4498
Yes	1.54 (1.37, 1.74) <0.0001	
No	1.64 (1.48, 1.83) <0.0001	
Hypertension		0.0727
Yes	1.38 (1.22, 1.57) <0.0001	
No	1.70 (1.53, 1.88) <0.0001	
CVD		0.1564
Yes	1.39 (1.10, 1.76) 0.0061	
No	1.62 (1.49, 1.76) <0.0001	
Diabetes		0.4117
Yes	1.44 (1.17, 1.77) 0.0006	
No	1.63 (1.49, 1.77) <0.0001	
Borderline	1.34 (0.79, 2.28) 0.2814	

OSA, obstructive sleep apnea; TyG-WHtR, triglyceride-glucose-waist to height ratio; CVD, cardiovascular disease. Adjusted for age; gender; race; education level; marital status; Smoking status; alcohol drinking; hypertension; CVD; diabetes.

Table 5. Baseline characteristics of participants after propensity score matching analysis.

Characteristics	Overall (n = 2826)	Non-OSA (n = 1413)	OSA (n = 1413)	P
Age (years)	50.29 ± 16.90	49.61 ± 17.71	50.97 ± 16.03	0.033
Gender (%)				0.071
Male	1394 (49.33)	673 (47.63)	721 (51.03)	
Female	1432 (50.67)	740 (52.37)	692 (48.97)	
Race (%)				0.943
Mexican American	371 (13.13)	182 (12.88)	189 (13.38)	
Other Hispanic	282 (9.98)	137 (9.70)	145 (10.26)	
Non-Hispanic White	969 (34.29)	484 (34.25)	485 (34.32)	
Non-Hispanic Black	710 (25.12)	356 (25.19)	354 (25.05)	
Other Races	494 (17.48)	254 (17.98)	240 (16.99)	
Education level (%)				0.489
Less than high school	497 (17.59)	238 (16.84)	259 (18.33)	
High school	667 (23.6)	330 (23.35)	337 (23.85)	
More than high school	1662 (58.81)	845 (59.80)	817 (57.82)	
Marital status (%)				0.244
Married/Living with a partner	1758 (62.21)	864 (61.15)	894 (63.27)	
Living alone	1068 (37.79)	549 (38.85)	519 (36.73)	
Smoking status (%)				0.119
Yes	1209 (42.78)	584 (41.33)	625 (44.23)	
No	1617 (57.22)	829 (58.67)	788 (55.77)	
Alcohol drinking (%)				0.943
Yes	2615 (92.53)	1307 (92.50)	1308 (92.57)	
No	211 (7.47)	106 (7.50)	105 (7.43)	
Hypertension (%)				0.001
Yes	1048 (37.08)	482 (34.11)	566 (40.06)	
No	1778 (62.92)	931 (65.89)	847 (59.94)	
CVD (%)				0.166
Yes	309 (10.93)	143 (10.12)	166 (11.75)	
No	2517 (89.07)	1270 (89.88)	1247 (88.25)	
Diabetes (%)				0.007
Yes	423 (14.97)	182 (12.88)	241 (17.06)	
No	2320 (82.09)	1187 (84.01)	1133 (80.18)	
Borderline	83 (2.94)	44 (3.11)	39 (2.76)	

OSA, obstructive sleep apnea; BMI, body mass index; WC, waist circumference; TG, triglycerides; TyG-WHtR, triglyceride-glucose-waist to height ratio; FBG, Fasting blood glucose; CVD, cardiovascular disease.

Table 6. Association between TyG-WHtR index and OSA after propensity score matching analysis.

Exposure	OR	95% CI	P-value
TyG-WHtR	1.60	(1.47, 1.74)	<0.001
TyG-WHtR index quartile			
Q1	Reference	Reference	Reference
Q2	1.85	(1.48, 2.31)	<0.001
Q3	2.74	(2.17, 3.45)	<0.001
Q4	3.83	(3.00, 4.89)	<0.001

Adjusted for: age; gender; race; education level; marital status; Smoking status; alcohol drinking; hypertension; CVD; diabetes.

Table 7. Association between TyG-WHtR index and OSA in sensitivity analysis.

Exposure	OR	95% CI	P-value
TyG-WHtR	1.68	(1.53, 1.84)	<0.001
TyG-WHtR index quartile			
Q1	Reference	Reference	Reference
Q2	1.99	(1.59, 2.50)	<0.001
Q3	3.31	(2.62, 4.18)	<0.001
Q4	3.94	(3.06, 5.08)	<0.001

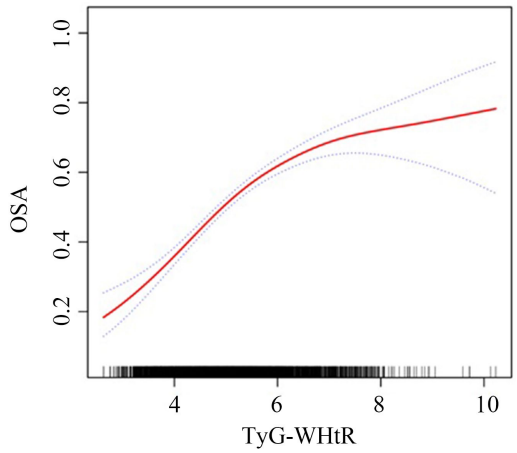

Figure 2. The solid red line illustrates the smooth curve fit between the variables, while the blue bands depict the 95% confidence interval derived from the fit.

PSM analysis yielded a matched cohort of 2826 participants with balanced baseline characteristics between OSA and non-OSA groups, confirming a consistent association between TyG-WHtR and risk of self-reported OSA (OR = 1.60, 95% CI: 1.47, 1.74; highest quartile OR = 3.83, 95% CI: 3.00, 4.89) (**Table 5**, **Table 6**). Sensitivity analysis excluding participants using hypoglycemic or lipid-lowering medications showed a robust association between TyG-WHtR and risk of self-

reported OSA (OR = 1.68, 95% CI: 1.53, 1.84; highest quartile OR = 3.94, 95% CI: 3.06, 5.08), aligning with primary findings (Table 7 and Table S2).

4. Discussion

This cross-sectional study of 3193 adults from NHANES 2017-2020 found that higher TyG-WHtR levels were associated with increased obstructive sleep apnea (OSA) risk, showing a dose-response relationship, a threshold effect, stronger associations in certain subgroups, and consistency across sensitivity analyses. TyG-WHtR combines information on insulin resistance and central obesity, so it may help us identify people who are more likely to develop OSA. Among them, WHtR mainly reflects the accumulation of abdominal fat, which may make the upper airway narrow and increase the possibility of collapse of the upper airway during sleep. The TyG index reflects more abnormalities in metabolic function [11] [12]. Previous studies have found that there is a certain correlation between TyG index and OSA, and TyG-BMI is also related to metabolic diseases [14] [18]. Because TyG-WHtR takes both metabolic status and central fat accumulation into account, it may provide more comprehensive information when assessing OSA risk, especially abdominal fat accumulation itself plays a more important role in the occurrence and development of OSA [23].

With the TyG-WHtR quartile level moving upwards, the proportion of OSA is also gradually increasing, suggesting that participants with relatively poor metabolic status and more central fat accumulation are indeed more likely to develop OSA. This result is consistent with previous studies that have shown that metabolic syndrome is closely related to the severity of OSA [9]. We also observed that there is a non-linear correlation between TyG-WHtR and OSA. One possible explanation is that when the level of TyG-WHtR is still relatively low, metabolic inflammation and changes in the upper airway may have begun to affect OSA; however, when TyG-WHtR increases to a certain extent, the increase in OSA risk may gradually weaken [23]. Previous studies have also reported that there is a similar nonlinear relationship between other metabolic indices and cardiac metabolic outcomes [24].

The association between TyG-WHtR and OSA is not exactly the same in different subgroups. This association is stronger among people who live alone than those who are married or live with a partner. One possible explanation is that people living alone are more likely to experience social isolation, psychological stress, or irregular sleep, all of which may affect metabolic health and sleep quality [25] [26]. But this explanation is so far only speculation. Compared with drinkers, the association in non-drinkers seems to be more obvious. Alcohol can reduce the tension of upper airway muscles and aggravate respiratory disorders during sleep, so it may affect the relationship between metabolic factors and OSA [9] [27]. In non-drinkers, metabolic dysfunction may play a relatively more important role in the above association. Similarly, this association is more pronounced among adults aged ≤ 60 years. This may suggest that the impact of metabolic abnormali-

ties on OSA in young adults will be more prominent; age-related changes in the structure and function of the upper airway may play a more important role as we age [22]. The association between TyG-WHtR and OSA is generally consistent in subgroups of different races and educational levels, which supports that it may have certain applicability in different populations. However, the association observed in other Hispanic populations is weaker, which may be related to genetic or environmental factors [5].

There may be several biological explanations for these associations mentioned above. TyG-WHtR can simultaneously reflect insulin resistance and central fat accumulation, both of which are likely to promote upper airway stenosis, systemic inflammation, and oxidative stress in OSA patients [28]. Triglyceride and glucose levels used to calculate the TyG index have also been found to be associated with some inflammatory markers in OSA patients, such as C-reactive protein and interleukin-6 [29]. Our results are consistent with a previous Korean study that also found a correlation between the TyG index and OSA [30]. Considering that TyG-WHtR has shown some efficacy in predicting cardiovascular and metabolic diseases, it may also be used for OSA screening [18] [31] [32].

There are still some limitations in this study. Similar to previous studies based on NHANES, we also determined OSA cases based on the symptoms reported by the participants themselves. Polysomnography is still the gold standard for the diagnosis of OSA, so this judgment method may bring recall bias [4]. Because this study uses a cross-sectional design, it is impossible to draw a conclusion on causality. In addition, unmeasured confounding factors such as genetic background and environmental exposure may also have an impact on the associations we observed. Although waist circumference and height are measured by trained staff, measurement errors may still affect the calculation results of TyG-WHtR. The data used in this study are all from the NHANES database in the United States, so these results may not be directly extended to other racial or ethnic groups with different eating habits, lifestyles and genetic characteristics [6]. In the future, it is still necessary to carry out some prospective studies using objective OSA evaluation methods, so as to verify our current results and further clarify the mechanisms involved. Overall, higher TyG-WHtR was associated with an increased likelihood of self-reported OSA. TyG-WHtR combines metabolic status and central obesity, and may provide a relatively simple way to identify those who need further assessment, especially in areas where polysomnography is more difficult to carry out. However, before its clinical screening value can be truly established, it is still necessary to further verify the above association through a prospective study using objective OSA diagnostic methods.

5. Conclusion

From the results of this study, participants with higher TyG-WHtR levels were more likely to report that they had OSA. Even after adjusting for a variety of potential confounding factors, this association is still statistically significant. We also

observed a dose-response relationship, and when TyG-WHtR was about 5.26, the association pattern between TyG-WHtR and OSA changed. However, because this study uses a cross-sectional design, it is not yet possible to infer whether there is a causal relationship between the two. In the future, it is still necessary to do some prospective studies to verify the results obtained now, and to further explore the potential mechanism.

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Author Contributions

FGL: Conceived study, designed methodology, analyzed data, investigated, drafted manuscript, edited final version. RX: Investigated, curated data, provided resources, edited manuscript, supervised. All authors contributed significantly, approved final manuscript, agreed on journal, and take full responsibility for the work.

Conflicts of Interest

The authors declare no conflict of interest.

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Supplemental Materials

Table S1. Variance Inflation Factor (VIF) for adjusted covariates in the association between TyG-WHtR and OSA.

Variable	VIF
Age	1.318559130
Gender	1.080056140
Education level	1.107719095
Marital status	1.035822574
Race	1.133868332
Smoking status	1.137745879
Alcohol drinking	1.091622518
Hypertension	1.321219222
CVD	1.151598927
Diabetes	1.133818170
TyG-WHtR	1.248076005

TyG-WHtR, triglyceride-glucose-waist to height ratio; cardiovascular disease.

Table S2. Baseline characteristics of participants in sensitivity analysis.

Characteristics	Overall (n = 2279)	Non-OSA (n = 1207)	OSA (n = 1072)	P
Age (years)	44.60 ± 15.83	42.65 ± 16.23	46.79 ± 15.08	<0.001
Gender (%)				<0.001
Male	1080 (47.39)	513 (42.50)	567 (52.89)	
Female	1199 (52.61)	694 (57.50)	505 (47.11)	
Race (%)				0.056
Mexican American	319 (14.00)	156 (12.92)	163 (15.21)	
Other Hispanic	224 (9.83)	107 (8.86)	117 (10.91)	
Non-Hispanic White	739 (32.43)	390 (32.31)	349 (32.56)	
Non-Hispanic Black	581 (25.49)	312 (25.85)	269 (25.09)	
Other Races	416 (18.25)	242 (20.05)	174 (16.23)	
Education level (%)				0.022
Less than high school	371 (16.28)	179 (14.83)	192 (17.91)	
High school	515 (22.60)	259 (21.46)	256 (23.88)	
More than high school	1393 (61.12)	769 (63.71)	624 (58.21)	
Marital status (%)				<0.001
Married/Living with a partner	1381 (60.60)	693 (57.42)	688 (64.18)	
Living alone	898 (39.40)	514 (42.58)	384 (35.82)	
Smoking status (%)				<0.001

Continued

Yes	893 (39.18)	421 (34.88)	472 (44.03)	
No	1386 (60.82)	786 (65.12)	600 (55.97)	
Alcohol drinking (%)				<0.001
Yes	2073 (90.96)	1071 (88.73)	1002 (93.47)	
No	206 (9.04)	136 (11.27)	70 (6.53)	
Hypertension (%)				<0.001
Yes	584 (25.63)	256 (21.21)	328 (30.60)	
No	1695 (74.37)	951 (78.79)	744 (69.40)	
CVD (%)				0.018
Yes	116 (5.09)	49 (4.06)	67 (6.25)	
No	2163 (94.91)	1158 (95.94)	1005 (93.75)	
Diabetes (%)				0.256
Yes	46 (2.02)	19 (1.57)	27 (2.52)	
No	2183 (95.79)	1160 (96.11)	1023 (95.43)	
Borderline	50 (2.19)	28 (2.32)	22 (2.05)	

OSA, obstructive sleep apnea; BMI, body mass index; WC, waist circumference; TG, triglycerides; TyG-WHtR, triglyceride-glucose-waist to height ratio; FBG, Fasting blood glucose; CVD, cardiovascular disease.