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Nonlinear association between the triglyceride-glucose index and diabetes mellitus in overweight and obese individuals: a cross-sectional retrospective analysis

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Abstract

Background The triglyceride-glucose (TyG) index is linked to both the development and progression of diabetes, while obesity remains a significant risk factor for this disease. However, the relationship between the TyG index and overweight or obese diabetes remains unclear.

Methods This study was a cross-sectional analysis of data from 40,633 participants with body mass index (BMI) ≥ 24 kg/m^2 who were screened from January 2018 to December 2023 at Henan Provincial People's Hospital. Participants were divided into groups of overweight or obese individuals with diabetes and those without diabetes according to the diabetes diagnostic criteria. The TyG index, the dependent variable, was determined using the equation ln [fasting triglycerides (mg/dL) × fasting glucose (mg/dL)/2]. We explored the association between TyG index and diabetes in overweight or obese individuals through multivariate logistic regression, subgroup analysis, generalized additive models, smoothed curve fitting, and analysis of threshold effects.

Results Patients who were overweight or obese and had diabetes had higher TyG index levels than those without diabetes. After adjusting for confounders, our findings indicated a significant association between the TyG index and the risk of diabetes in overweight or obese individuals [odds ratio (OR) = 7.38, 95% confidence interval (CI): 6.98–7.81]. There was a J-shaped nonlinear association between TyG index and diabetes. When TyG index was > 4.46, the risk of diabetes increased sharply. Notably, a high baseline TyG index (Q4 group) correlated with a notably greater risk of diabetes than did the Q1 group, with an OR of 22.72 (95% CI: 20.52–25.16). Subgroup analysis revealed that the

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association between TyG and diabetes was stronger in females than in males (OR = 7.57, 95% CI: 6.76–8.48,), more significant in individuals with a BMI of 24–28 kg/m^2 than in those with a BMI ≥ 28 kg/m^2 (OR = 8.40, 95% CI: 7.83–9.02), and increased with age (OR = 8.15, 95% CI: 7.25–9.17) (all *P* for interaction < 0.001).

Conclusion Among overweight or obese individuals, a higher TyG index is associated with an elevated risk of diabetes, especially when TyG is > 4.46. Furthermore, factors such as sex, age, and BMI significantly influence the risk of diabetes in overweight or obese individuals. Specifically, older women with a BMI of 24–28 kg/m^2 are at a greater risk of diabetes under similar TyG index conditions.

Keywords Triglyceride-glucose index, BMI, Adiposity, Cross-sectional studies

Introduction

Diabetes poses a significant global public health challenge and is characterized by a complex interplay of endocrine and metabolic factors driven by chronic positive energy imbalance [1]. Recent statistics show that a substantial number of 529 million people worldwide were affected by diabetes in 2021, and this number is projected to rise steeply to approximately 1.31 billion by 2050 [2]. Notably, China has the largest diabetic population, with 140 million people by 2021 [3]. Over the past two decades, the global prevalence of diabetes has doubled, mainly owing to the obesity epidemic [4]. The effect of high body mass index (BMI) on disability or mortality among individuals with type 2 diabetes has increased by 24.3% worldwide between 1990 and 2021 [2]. Therefore, it is crucial to identify high-risk groups early and develop effective primary prevention strategies to address the increasing prevalence of diabetes among the obese population.

The triglyceride glucose (TyG) index, which is derived from triglycerides and fasting glucose, has emerged as a significant predictor of insulin resistance [5]. The TyG index was first proposed by SimalMendia et al. in 2008 [6] and is known for its affordability, accessibility, and wide-ranging applications in the study of glycolipid metabolism [7, 8], which has demonstrated strong predictive capability in various diseases, including obstructive sleep apnea [9]. Compared with other indicators, the TyG index has demonstrated superior discriminatory power in identifying individuals with diabetes in the general population [10]. Notably, associations between the TyG index and diabetes incidence have mainly been observed in individuals with normal weight [11], those with diabetes and coronary artery disease [12, 13], hospitalized patients with diabetes complications [14], and diabetic individuals with cognitive impairment [15]. However, obesity is the main cause of insulin resistance in diabetic patients, and it is an independent risk factor for type 2 diabetes, its complications, and even all-cause death [16, 17]. However, the correlation between TyG index and overweight or obese individuals with diabetes remains unclear.

Therefore, this study aimed to investigate the association between the TyG index and diabetes in overweight or obese individuals and to assess its ability to predict diabetes risk. The aim was to provide targeted recommendations for the prevention and management of diabetes mellitus and to contribute data to support the formulation of appropriate clinical prevention and control policies.

Materials and methods

Individuals and the criteria for inclusion

Research data were extracted from the medical records of individuals who underwent health screenings at the Health Management Center of Henan Provincial People's Hospital between January 2018 and December 2023. Ethical approval for the study was obtained from the Ethics Committee of Henan Provincial People's Hospital (Approval Code: 2021 Lunar Review No. 68), and informed consent was obtained from all the participants. The dataset was registered on clinicaltrials.gov (Registration Code: NCT03699228) and affiliated with the China Health Quantitative CT Big Data Research Project Group. Participants were selected based on the following specific criteria: (1) age between 20 and 80 years; (2) BMI ≥ 24 kg/m^2; (3) complete general and questionnaire information; and (4) complete fasting blood glucose (FBG) and glycosylated hemoglobin (HbA1c) levels. The exclusion criteria were as follows: (1) history of any form of cancer, psychiatric or cognitive disorders in women, mobility impairments, pregnancy, or breastfeeding; (2) previous or current pancreas-related disorders; (3) extreme values in the test results; (4) previous or current other metabolic disorders (e.g., primary aldosteronism, pheochromocytoma, liver injury, abnormal thyroid function); and (5) unknown diabetic status. A total of 267,034 participants were included in this study, but only 47,916 met the criteria for further analysis, which included a BMI ≥ 24 kg/m^2, complete glycated hemoglobin, fasting glucose, and medical history data. The participants were further categorized into diabetic (13,996 patients) and nondiabetic (33,918 patients) groups based on the diagnostic criteria for diabetes mellitus. Both groups were screened based on the completeness of their clinical data. Ultimately, 40,633 participants were included in the final analysis, with 10,532 in the diabetic group and 30,101

in the nondiabetic group. A professional researcher collected comprehensive data from all participants, including age, sex, ethnicity, medical history, and medication history. The participant screening process is illustrated in Fig. 1.

Definitions of the exposure and outcome variables

The exposure variable, TyG, was calculated as Ln [triglycerides (mg/dL) × glucose (mg/dL)/2]. The outcome variable was overweight or obesity, which was defined according to the American Diabetes Association's diagnostic criteria: self-reported diagnosis, use of insulin or oral hypoglycemic medication, HbA1c≥6.5%, or FBG≥7 mmol/L [18].

BMI was calculated as weight divided by height squared (kg/m^2). Additionally, BMI was categorized according to the Chinese national standard into thresholds for overweight (24≤BMI<27.9 kg/m^2) and obesity (BMI≥28 kg/m^2) [19].

Hypertension was defined as a systolic blood pressure (SBP)≥140 mmHg or diastolic blood pressure (DBP)≥90 mmHg, self-reported hypertension, antihypertensive medication use, or antihypertensive therapy [20]. Based on previous studies, total serum protein was divided into three groups using 60 and 80 as cut-off points. Elevated alanine aminotransferase (ALT), aspartate transaminase (AST), and glutamyl transpeptidase (GGT) levels were defined as values exceeding 40 U/L, and these cut-off points were used to categorize ALT, AST, and GGT levels, respectively, into two groups. Alkaline phosphatase (ALP) was divided into three groups using 40 and 150 as cutoff points [21]. Total bilirubin, creatinine (Cre), and uric acid (UA) levels were divided into three groups based on tertiles.

Laboratory measurements

Prior to conducting the surveys, all researchers underwent standardized training to ensure impartiality and accuracy of the data. A standardized questionnaire was used to collect the necessary data from the participants. The questionnaire included disclosure of participants' medical history, such as previous or current diabetes, various cancers and endocrine disorders, and recent medication use within the past two weeks. Once the questionnaire was completed, the researcher organized, summarized, and verified the data.

At 8 a.m., after an overnight fast, venous blood samples were collected from the participants to measure various biochemical markers, including total protein, total bilirubin, ALT, AST, GGT, ALP, Cre, UA, total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), FBG, and HbA1c. Blood glucose levels were measured using an Olympus® AU 5400 automated biochemical analyzer (Olympus Corporation, Japan, Shizuoka Prefecture). Standard laboratory procedures were performed to evaluate the remaining indicators.

To measure the SBP and DBP, the research staff used an electronic sphygmomanometer (Omron Company, OMRON U30, Kyoto, Japan). The right arm was placed in a semiflexed position at heart level during the measurement.

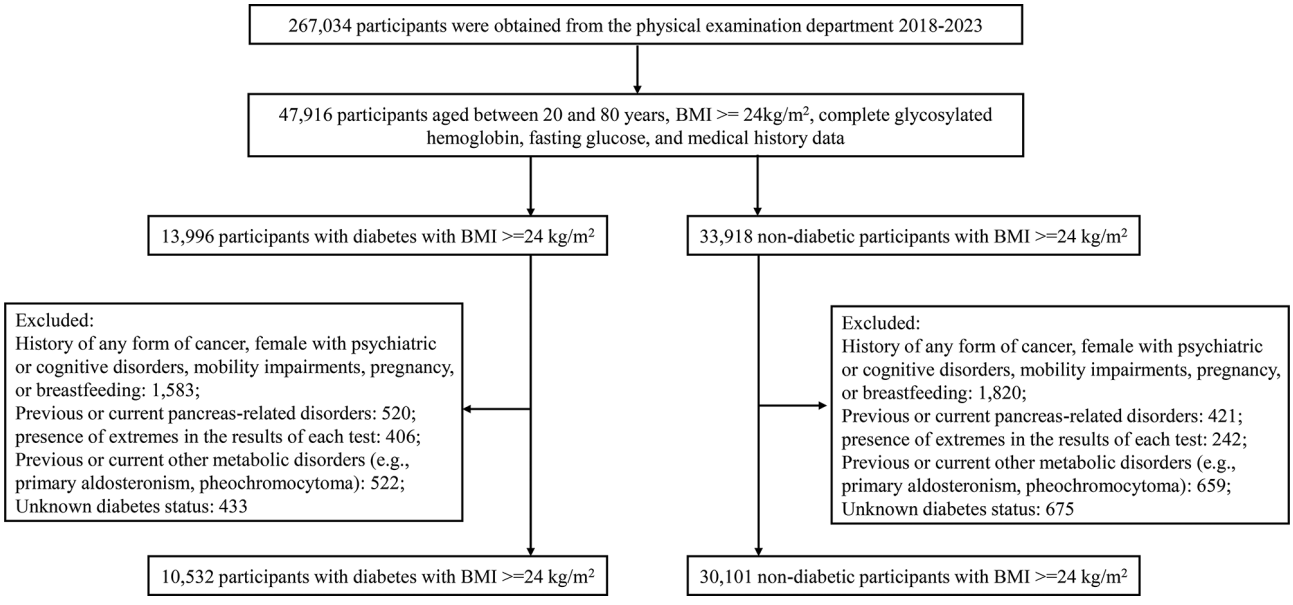

Fig. 1 Flowchart of participants selection

Potential covariates

Covariate data were collected as follows: (1) demographic data, including sex, ethnicity, occupation, and age; (2) physical examination parameters, including BMI, SBP, and DBP; (3) medical conditions, including a history of diseases, such as diabetes, stroke, and cancer; and (4) laboratory indicators, including total protein, total bilirubin, ALT, AST, GGT, ALP, Cre, and UA.

Statistical analysis

Statistical analysis was performed using R, version 4.2.0 (R Foundation) and EmpowerStats (http://www.empowerstats.com, X&Y Solutions, Inc., Boston, MA, USA). A significance level of $P<0.05$ was used for all statistical tests.

For each dataset, a normality test was conducted to identify the continuous variables. Normally distributed continuous variables are presented as mean±standard deviation, whereas skewed continuous variables are described as medians (interquartile ranges). Inter-group disparities were assessed using t-tests or rank-sum tests. Categorical variables are depicted as frequencies with accompanying percentages, and comparisons were conducted using the chi-square test or Fisher's exact test.

First, the effect of each variable on the risk of diabetes was assessed using univariate logistic regression models, and the odds ratios (ORs) and corresponding 95% confidence intervals (CIs) were calculated. Considering confounding variables, multivariate logistic regression analysis with stepwise regression was used to exclude dependent variables with a variance inflation factor (VIF)>10 to investigate the association between TyG index and the incidence of diabetes in overweight or obese participants. The crude model did not include covariate adjustment. Model I was adjusted for BMI, age, sex, occupation, and ethnicity, whereas Model II was adjusted for each covariate individually.

In addition, the TyG index was converted into quartiles, which formed the basis of the final model to ensure reliability of the results. The model evaluated the association between quartiles and diabetes, using the lowest quartile as a reference. Subsequently, a generalized additive model based on smoothed curve fitting was used to describe the dose-response relationship between the TyG index and the risk of overweight or obese diabetes patients. A two-stage logistic regression model was constructed by analyzing the data on either side of the inflection point to reveal potential nonlinear relationships. The log-likelihood ratio was used to select the most appropriate model to describe the relationship between the TyG index and the risk of overweight or obese patients with diabetes. Stratified analyses and interaction tests were also performed according to Model II to explore other factors influencing the relationship between the TyG index and diabetes development.

Results

Baseline details about the participants

There were 40,633 overweight or obese participants, including 10,532 with diabetes and 30,101 without diabetes. The prevalence of diabetes was 25.92%. Among overweight or obese individuals, the TyG index was significantly higher in the group with diabetes than in the group without diabetes (Fig. 2). Table 1 provides a description of the baseline characteristics of the study population categorized according to diabetes diagnosis. The overweight or obese group with diabetes mostly consisted of males, corporate employees, older individuals,

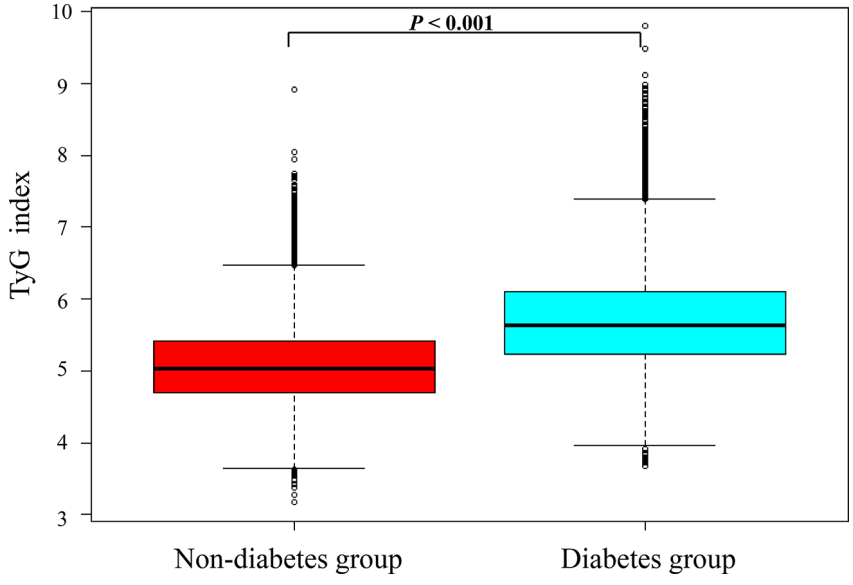

Fig. 2 TyG index in overweight or obese non-diabetes and diabetes group. $P<0.001$, as compared with non-diabetes group

Table 1 Baseline characteristics of overweight or obese participants by diabetes status

Variables	Overall	Non-diabetes	Diabetes	*P*-value
N	40,633	30,101	10,532	
Sex, n (%)				< 0.001
Female	11,050 (27.19)	7914 (26.29)	3136 (29.78)	
Male	29,583 (72.81)	22,187 (73.71)	7396 (70.22)	
Ethnic group, n (%)				0.935
Non-han	637 (1.57)	471 (1.56)	166 (1.58)	
Han	39,996 (98.43)	29,630 (98.44)	10,366 (98.42)	
Occupation, n (%)				< 0.001
Unemployment	13,745 (33.83)	11,193 (37.18)	2552 (24.23)	
Doctors	817 (2.01)	290 (0.96)	527 (5.00)	
Staff members	26,071 (64.16)	18,618 (61.85)	7453 (70.77)	
Age, years	49.61 ± 12.54	47.17 ± 11.90	56.60 ± 11.64	< 0.001
BMI, kg/m^2	27.15 ± 2.58	27.00 ± 2.46	27.60 ± 2.86	< 0.001
Hypertension, n (%)				< 0.001
No	26,608 (65.48)	21,503 (71.44)	5105 (48.47)	
Yes	14,025 (34.52)	8598 (28.56)	5427 (51.53)	
Total protein, g/L	71.97 ± 4.25	71.90 ± 4.06	72.17 ± 4.75	< 0.001
Total bilirubin, μmol/L	12.25 ± 5.59	12.34 ± 5.52	11.99 ± 5.79	< 0.001
ALT, U/L	23.40 (16.90,34.50)	22.76 (16.80,34.40)	23.40 (17.00,34.70)	< 0.001
AST, U/L	21.00 (17.50,26.10)	20.70 (17.70,25.90)	21.02 (16.90,26.70)	< 0.001
GGT, U/L	29.20 (20.30,46.10)	28.50 (19.70,44.80)	31.30 (22.00,50.30)	< 0.001
ALP, U/L	72.38 ± 20.84	70.46 ± 19.12	77.87 ± 24.31	< 0.001
Cre, μmol/L	69.52 ± 20.12	70.30 ± 17.85	67.27 ± 25.36	< 0.001
UA, μmol/L	361.14 ± 92.06	369.48 ± 91.28	337.32 ± 90.10	< 0.001
TC, mmol/L	4.95 ± 1.00	4.85 ± 0.93	4.96 ± 1.18	0.007
LDL-C, mmol/L	2.91 ± 0.77	2.93 ± 0.74	2.86 ± 0.86	< 0.001
TG, mmol/L	1.76 (1.26,2.55)	1.69 (1.22,2.41)	2.00 (1.40,2.95)	< 0.001
HDL-C, mmol/L	1.21 ± 0.26	1.23 ± 0.26	1.16 ± 0.25	< 0.001
FBG, mmol/L	5.91 ± 1.93	5.09 ± 0.55	8.24 ± 2.48	< 0.001
HbA1c, %	6.07 ± 1.05	5.58 ± 0.40	7.49 ± 1.04	< 0.001
TyG	5.25 ± 0.67	5.08 ± 0.56	5.72 ± 0.72	< 0.001

BMI: Body mass index; ALT: Alanine aminotransferase; AST: Aspartate transaminase; GGT: Glutamyl transpeptidase; ALP: Alkaline phosphatase; Cre: CREATININE; UA: Uric acid; TC: Total cholesterol; LDL-C: Low-density lipoprotein cholesterol; TG: Triglycerides; HDL-C: High-density lipoprotein cholesterol; FBG: Fasting blood glucose; HbA1c: Glycosylated hemoglobin. TyG: Triglyceride glucose

and those with hypertension. Additionally, diabetic participants had higher BMIs, total protein, ALT, AST, GGT, ALP, TC, TG, FBG, HbA1c, and TyG levels, and lower total bilirubin, Cre, UA, LDL-C, and HDL-C levels than non-diabetic participants (all $P<0.05$).

Relationships between the TyG index and overweight or obese diabetic individuals according to the different models

The relationships between the TyG index and overweight or obese diabetic populations in different models are presented in Table 2, summarizing the results of the univariate logistic regression that aided in selecting covariates for the subsequent multivariate regression analysis. In the multivariate logistic regression analysis, the ethnic group was excluded as a covariate. The independent relationship between TyG index and diabetes status was further confirmed using multivariate logistic regression analysis. As shown in Table 3, in both Model I (OR=6.85, 95% CI: 6.51–7.20, $P<0.001$) and Model II (OR=7.38, 95% CI: 6.98–7.81, $P<0.001$), the continuous TyG index remained independently associated with the risk of diabetes after accounting for confounding factors. Specifically, for every 1-unit increase in the TyG index, the risk of diabetes increased by 7.38 ($P<0.001$). To convert continuous variables into categorical variables, the quartiles of the TyG index were used. After adjusting for multiple confounders, the risk of diabetes was 21.72 times greater in the group with the highest TyG index than that in the group with the lowest TyG index ($P<0.001$).

Subsequently, the association between the TyG index and diabetes mellitus was analyzed through smooth curve fitting, and a nonlinear relationship was discovered (Fig. 3A). The results of the threshold-effect analysis are presented in Table 4. When TyG was ≥4.46, the risk of diabetes increased by 7.56 times for each unit increase

Table 2 Univariate logistic analysis for predicting overweight or obese diabetes

	Statistics	OR (95%CI)	*P*-value
Sex, *n* (%)			
Female	11,050 (27.19)	1.0	
Male	19,583 (72.81)	0.84 (0.80,0.88)	< 0.001
Ethnic group, n (%)			
Non-han	637 (1.57)	1.0	
Han	39,996 (98.43)	0.99 (0.83, 1.19)	0.935
Occupation, n (%)			
Unemployment	13,745 (33.83)	1.0	
Doctors	817 (2.01)	7.97 (6.86, 9.26)	< 0.001
Staff members	26,071 (64.16)	1.76 (1.67, 1.85)	< 0.001
Age, years	49.61 ± 12.54	1.07 (1.07, 1.07)	< 0.001
BMI, kg/m^2	27.15 ± 2.58	1.09 (1.08, 1.10)	< 0.001
Hypertension, n (%)			
No	26,608 (65.48)	1.0	
Yes	14,025 (34.52)	2.66 (2.54, 2.78)	< 0.001
Total protein, g/L	71.97 ± 4.25	1.01 (1.01, 1.02)	< 0.001
Total bilirubin, μmol/L	12.25 ± 5.59	0.99 (0.98, 0.99)	< 0.001
ALT, U/L	23.40 (16.90, 34.50)	1.00 (1.00, 1.00)	< 0.001
AST, U/L	21.00 (17.50, 26.10)	1.00 (1.00, 1.01)	< 0.001
GGT, U/L	29.20 (20.30, 46.10)	1.00 (1.00, 1.00)	< 0.001
ALP, U/L	72.38 ± 20.84	1.02 (1.02, 1.02)	< 0.001
Cre, μmol/L	69.52 ± 20.12	0.99 (0.98, 0.99)	< 0.001
UA, μmol/L	361.14 ± 92.06	1.00 (1.00, 1.00)	< 0.001
TC, mmol/L	4.95 ± 1.00	1.01 (1.00, 1.04)	< 0.001
LDL-C, mmol/L	2.91 ± 0.77	0.88 (0.85, 0.90)	< 0.001
TG, mmol/L	1.76 (1.26, 2.55)	1.18 (1.16, 1.19)	< 0.001
HDL-C, mmol/L	1.21 ± 0.26	0.37 (0.33, 0.40)	< 0.001
FBG, mmol/L	5.91 ± 1.93	13.15 (12.43, 13.91)	< 0.001
HbA1c, %	6.07 ± 1.05	982.16 (799.58, 1206.44)	< 0.001
TyG	5.25 ± 0.67	5.06 4.85, 5.28()	< 0.001

BMI: Body mass index; ALT: Alanine aminotransferase; AST: Aspartate transaminase; GGT: Glutamyl transpeptidase; ALP: Alkaline phosphatase; Cre: Creatinine; UA: Uric acid; TC: Total cholesterol; LDL-C: Low-density lipoprotein cholesterol; TG: Triglycerides; HDL-C: High-density lipoprotein cholesterol; FBG: Fasting blood glucose; HbA1c: Glycosylated hemoglobin. OR: Odds ratio; CI: Confidence interval

Table 3 Relationship between TyG index and overweight or obese diabetes in different models

	Crude model		Model I		Model II	
	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value
TyG index	5.06 (4.85, 5.28)	< 0.001	6.85 (6.51, 7.20)	< 0.001	7.38 (6.98, 7.81)	< 0.001
Q1	Reference		Reference		Reference	
Q2	2.53 (2.31, 2.78)	< 0.001	2.45 (2.22, 2.71)	< 0.001	2.46 (2.22, 2.73)	< 0.001
Q3	5.14 (4.71, 5.62)	< 0.001	5.65 (5.14, 6.21)	< 0.001	5.85 (5.30, 6.45)	< 0.001
Q4	15.68 (14.39, 17.10)	< 0.001	22.07 (20.06, 24.27)	< 0.001	22.72 (20.52, 25.16)	< 0.001
P for trend	2.50 (2.43, 2.56)	< 0.001	2.86 (2.78, 2.95)	< 0.001	2.88 (2.80, 2.97)	< 0.001

Crude model: No adjustment for model variables. Model I was adjusted for age, sex, and occupation. Model II was adjusted for all covariates. OR: Odds ratio; CI: confidence interval

in TyG index. When TyG was < 4.46, the increase in the risk of overweight or obese diabetes was not significant ($P > 0.05$).

Subgroup analysis

In addition to age, consistency was observed in the subgroup analyses (Fig. 4. Interactions were not significant when stratified by ethnic group, occupation, hypertension, total protein, total bilirubin, ALT, AST, GGT, ALP, Cre, or UA (P for interaction > 0.05). However, a significant interaction was noted for sex, age, and BMI (P for interaction < 0.001). Stratification by sex revealed that the risk of diabetes was greater in females than in males who were overweight or obese for the same TyG index size (Fig. 3B; Table 4), with the segmentation breakpoint being greater in females (K = 4.49) than in males

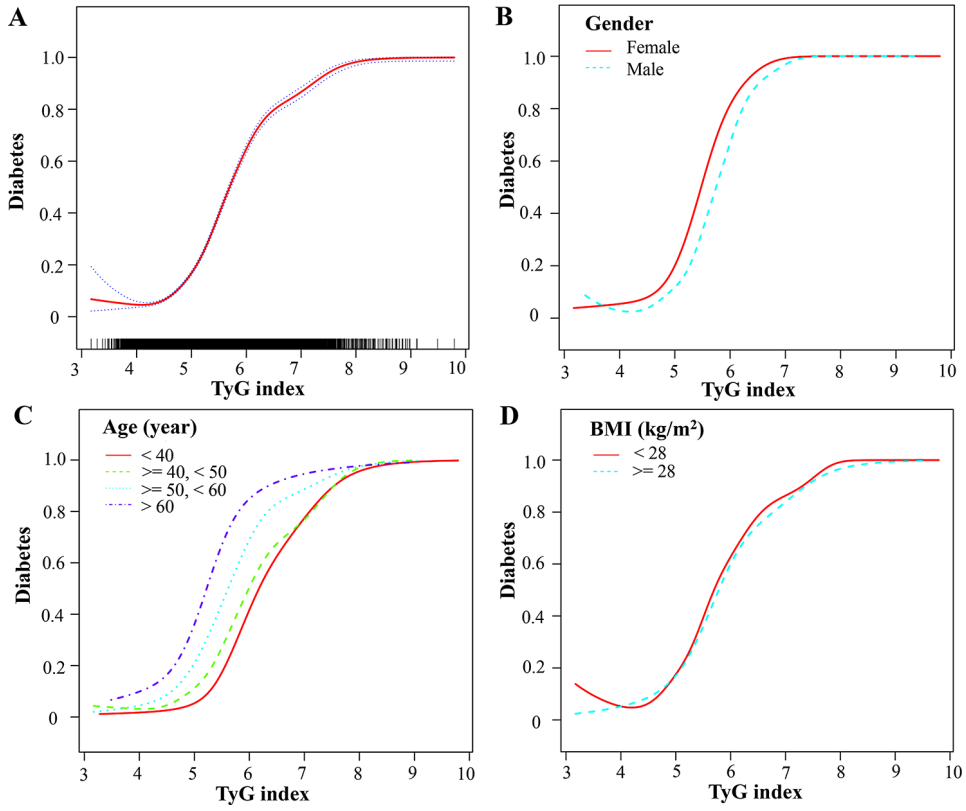

Fig. 3 Generalized additive model with fitting smoothness for the dose–response relationship between TyG index and overweight or obese diabetes risk in different subgroups. **A**: Whole population; **B**: Sex-specific groups; **C**: People of different ages; **D**: People with different BMI. BMI, body mass index

Table 4 The result of the two-piecewise logistic regression model

	Linear regression	Break point	< K	> K	LLR test
	OR (95%CI)	(K)	OR (95%CI)	OR (95%CI)	*P*
Overall	7.38 (6.98, 7.81)	4.46	2.59 (1.34, 4.97)	7.56 (7.14, 8.01)	< 0.001*
Sex					
Female	7.57 (6.76, 8.48)	4.31	1.65 (0.62, 4.41)	8.02 (7.11, 9.06)	0.005*
Male	7.38 (6.92, 7.88)	4.49	1.01 (0.31, 3.29)	7.52 (7.04, 8.03)	0.002*
Age (year)					
< 40	5.89 (4.87, 7.07)	5.05	2.75 (1.01, 4.49)	5.95 (4.44, 7.28)	0.036*
>= 40, < 50	6.04 (5.41, 6.73)	4.71	3.10 (2.49, 5.72)	6.22 (5.55, 6.97)	< 0.001*
>= 50, < 60	7.39 (6.72, 8.13)	4.63	3.40 (2.53, 5.39)	7.50 (6.78, 8.30)	< 0.001*
>= 60	8.15 (7.25, 9.17)	4.34	1.57 (1.16, 2.06)	8.65 (7.65, 9.77)	< 0.001*
BMI (kg/m²)					
< 28	8.40 (7.83, 9.02)	4.23	0.51 (0.13, 2.07)	8.59 (7.99, 9.23)	< 0.001*
>= 28	6.12 (5.59, 6.70)	4.56	3.14 (1.09, 9.07)	6.22 (5.65, 6.84)	< 0.001*

All covariates were adjusted in this model. OR, odds ratio; CI, confidence interval

*$P < 0.05$

(K = 4.31). Subgroup analyses by age indicated a progressive increase in the risk of diabetes increased with age for the same TyG index (Table 4; Fig. 3C). Specifically, when TyG was ≥4.34 in individuals aged ≥ 60 years, the risk of overweight or obese diabetes increased by 8.65 times with each unit increase in the TyG index, which was 2.7 times greater than for those aged < 40 years. Stratification by BMI revealed that the risk of developing diabetes was lower in the obese population (BMI ≥ 28 kg/m^2) than in the overweight population (BMI < 28 kg/m^2) for the same TyG index (Table 4; Fig. 3D).

Discussion

In this study of participants undergoing health screenings, we observed a consistent association between the TyG index and an increased risk of overweight or obese

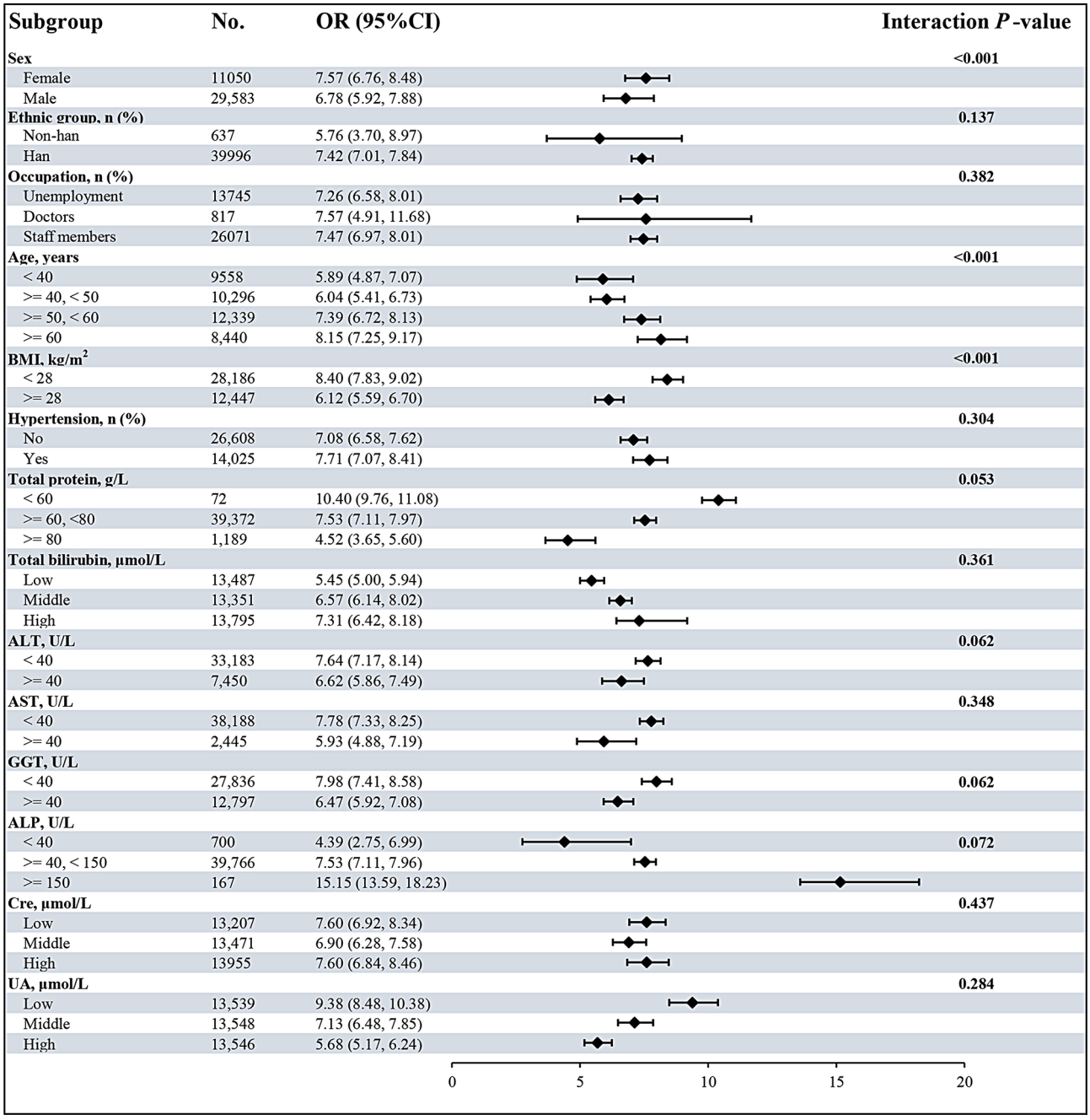

Fig. 4 The relationship between TyG index of overweight or obese diabetes according to different subgroups. BMI, body mass index. ALT, alanine aminotransferase; AST, aspartate transaminase; GGT, glutamyl transpeptidase; ALP, Alkaline phosphatase; Cre, Creatinine; UA, Uric acid, OR, odds ratio; CI, confidence interval

diabetes, even after adjusting for confounding factors. The risk of overweight or obese diabetes increases with age. Furthermore, we found that the TyG index posed a greater risk for overweight or obese diabetes in females than in males and a greater risk in the overweight (24 kg/$m^2 \leq$BMI$<$28 kg/m^2) population than in the obese (28 kg/$m^2 \leq$BMI) population. Interestingly, we also identified a J-shaped curve, with an inflection point at 4.46, when examining the relationship between the TyG index and overweight or obese diabetes patients. The findings of this study will assist primary care physicians in the early identification of diabetes risk among overweight or obese individuals. By formulating targeted intervention strategies for different subgroups, this research holds significant implications for the prevention and treatment of diabetes in the overweight and obese population.

Previous research has demonstrated that insulin resistance is a key characteristic of type 2 diabetes mellitus,

which often appears years before the clinical diagnosis [22]. It is characterized by reduced sensitivity and responsiveness to insulin. The TyG index has emerged as the preferred tool for assessing insulin resistance [7]. In a longitudinal study of 5,354 middle-aged nondiabetic Koreans, individuals in the highest quartile of the TyG index had a more than four-fold increased risk of developing diabetes compared to those in the lowest quartile (OR=4.095; 95% CI 2.701–6.207). This highlights the potential usefulness of the TyG index for identifying individuals with heightened diabetes risk [23]. Similarly, in another investigation involving 4,820 participants, the TyG index demonstrated superior predictive capacity (AUC: 0.75, 95% CI 0.7–0.81) for diagnosing diabetes compared to FBG measurements (AUC: 0.66, 95% CI 0.60–0.72) and TG levels (AUC: 0.71, 95% CI 0.65–0.77) [24]. These collective findings suggest the potential value of the TyG index for identifying individuals predisposed to future diabetes development.

Considering the effect of obesity on the incidence of diabetes, this study specifically focused on overweight or obese individuals to investigate the relationship between the TyG index and diabetes. The findings of our study revealed that in overweight or obese individuals, there was a significant increase in the risk of diabetes, with a TyG index greater than 4.46. Previous studies have demonstrated that the risk of diabetes in middle-aged and older people, categorized into four quartiles, increases as the TyG index increases [25]. A meta-analysis of 14 studies revealed a nonlinear correlation between TyG index and the risk of diabetes after adjusting for confounding factors. The response curve showed a steeper trend at a TyG index exceeding 8.6, which aligns with the results of our study [26]. Furthermore, our study revealed that the association between TyG index and the risk of overweight or obese individuals developing diabetes was stronger than that reported in a cross-sectional study conducted by Zhang et al. in 2016. Their study, which focused on a general community population in China, revealed an odds ratio of 9.04 for the fourth quartile of the TyG index in relation to diabetes after accounting for confounding variables [27]. Another longitudinal study conducted in the Chinese Physical Examination Cohort revealed a causal relationship between the combined indicators of TyG and BMI and the development of diabetes after eliminating other confounding variables [28]. Weight gain is widely acknowledged to play a crucial role in the incidence of diabetes. Zhang et al. discovered that being overweight or obese was a significant risk factor for impaired glucose tolerance, as shown in a prospective study involving a Chinese multicenter population [29]. The onset of type 2 diabetes occurs when pancreatic β-cells struggle to handle the increased insulin demand caused by insulin resistance. Obesity often leads to nutrient overload, resulting in the release of reactive oxygen species and subsequent oxidative stress [30]. This, in turn, contributes to an increased influx of endoplasmic reticulum stress, exacerbating the toxic effects of lipids on β cells [31]. Therefore, the TyG index may be a more predictive indicator for the risk of developing diabetes in overweight or obese individuals. Furthermore, our findings are consistent with those of previous studies on TyG index and other cardiometabolic diseases. A study based on large cohorts revealed a significant association between an increased TyG index and the risk of heart failure [32]. Another investigation utilizing the National Health and Nutrition Examination Survey (NHANES) database demonstrated a link between the TyG index and risk of myocardial infarction [33]. In research involving patients with acute decompensated heart failure, high TyG index levels were associated with poorer prognoses [34]. These studies underscore the potential role of the TyG index in identifying risks associated with cardiometabolic diseases, and our research extends these findings to diabetes. Although the specific mechanisms of these associations may vary, collectively, these studies support the view that the TyG index is an important tool for assessing the risk of metabolic abnormalities.

The subgroup analyses in this study revealed intriguing phenomena. There were significant differences in the risk of TyG and overweight or obese diabetes based on sex, age, and BMI. In the subgroups stratified by sex, the risk of TyG and diabetes was greater in overweight or obese females than in males. A longitudinal study conducted using data from the China Diabetes Database indicated that the TyG index is a more effective predictor of diabetes in women than in men [10]. Moreover, through an analysis of a sample comprising 201,298 health-screened Chinese adults, Li et al. demonstrated that an elevated TyG index is associated with a greater risk of diabetes in women than in men [35]. Similarly, a study focusing on a rural cohort of normal-weight Chinese individuals revealed that the TyG index is associated with a greater risk of diabetes in women than in men [11]. The findings of our study are consistent with previously reported results. Previous studies have established that obese individuals with diabetes are characterized by a state of inflammation [36]. Notably, this inflammatory state is more pronounced in women with diabetes than in men [37]. Hyperinflammation affects lipid metabolism, leading to increased TG levels and contributing to the development of diabetes [36, 38]. Additionally, sex differences exist in terms of blood glucose abnormalities, with impaired glucose tolerance being more prevalent in women [39]. Moreover, obese women exhibit increased sensitivity to diabetes [40]. Furthermore, women generally have higher levels of hepatocellular lipids both during fasting periods and after glucose and lipid loading than

do men. This disparity contributes to metabolic disorders [41]. Collectively, these factors increased the risk of diabetes in women with a TyG index.

In the age-stratified subgroups, the risk of TyG-associated diabetes was significantly greater in individuals aged ≥ 60 years who were overweight or obese than in those aged < 40 years. Age is a well-known risk factor for diabetes, and previous studies have demonstrated that the prevalence of diabetes in China increases with age [42]. Older age groups and individuals with obesity have a greater risk of developing diabetes [43]. According to NHANES, the overall prevalence of diabetes is estimated to be 5.0% for adults under 45 years of age, 17.5% for adults aged 45–64, and 33.0% for adults aged 65 years and older [44]. Compared to younger patients, elderly patients who are overweight or obese may have poorer organ regulation, redistribution of adipose tissue, and decreased tolerance of insulin resistance. Moreover, older adults who are overweight or obese may have difficulty regulating their body or monitoring their own blood glucose and triglyceride levels, thereby increasing the association between TyG index and diabetes risk. In contrast, another study conducted on health-screened Chinese adults revealed that the TyG index was most strongly associated with the risk of diabetes in individuals aged < 40 years [35]. This inconsistency may be attributed to the high BMI of the participants in that study, and the obesity status may have influenced the relationship between age and diabetes risk.

Interestingly, in this study, the risk of TyG and diabetes was greater in overweight individuals than in obese individuals in BMI-stratified subgroups. Out of the total participants, 10,532 were diagnosed with diabetes. Among these, 6626 were in the overweight group and 3906 were in the obese group. This finding is consistent with a separate study conducted by the China Health Screening Program, which revealed that the TyG index and diabetes were more prevalent in individuals with BMI between 24 and 28 kg/m^2 than in those with BMI ≥ 28 kg/m^2 [35]. This phenomenon may be attributed to subtle changes in body composition resulting from alterations in social structure, lifestyle, and dietary habits, leading to significant increases in fat storage and the accumulation of visceral fat [16, 45]. The use of BMI as a diagnostic measure for clinical obesity solely captures overall obesity and fails to identify high-risk individuals with a substantial amount of visceral fat [46]. Thus, relying solely on body BMI may not adequately distinguish different levels of obesity [47], and using BMI alone to measure obesity has its limitations. Higher amounts of visceral fat can be transported and stored in the liver through the portal vein system, subsequently increasing hepatic triglyceride levels, reducing insulin absorption, causing metabolic disturbances, and increasing the risk of insulin resistance. Additionally, macrophages in the visceral adipose tissue secrete cytokines that stimulate chronic inflammation, contributing to the development of insulin resistance [48].

The strengths of this study include a large sample size, which provided robust statistical support for adjusted logistic regression analysis. Furthermore, this study addresses this research gap by examining the association between the TyG index and diabetes risk in individuals with BMI ≥ 24 kg/m^2. This study explored the relationship between TyG index and overweight or obese diabetes through subgroup analyses and interaction tests, providing valuable insights for diabetes prevention and screening in different population subgroups. It is important to acknowledge the limitations of this study. First, owing to its retrospective design, a causal relationship between the TyG index and overweight or obese diabetes could not be determined. Second, while efforts were made to collect comprehensive data on confounding variables, there may still be unadjusted variables that could introduce residual confounders such as smoking and alcohol consumption. Furthermore, using BMI ≥ 28 kg/m^2 as the threshold for obesity aligns with Chinese classification standards, yet the world health organization defines obesity as BMI > 30 kg/m^2 [49], this may limit its applicability in other ethnic groups. Finally, this single-center study focused on a particular health-screening population, which limits the generalizability of the findings to other groups. These limitations highlight areas for future research aimed at understanding the factors that influence diabetes.

Conclusion

The current study demonstrated that the TyG index is independently associated with an increased risk of diabetes in overweight or obese adults undergoing health screening. The risk of diabetes increased abruptly when TyG level was > 4.46. Notably, this association was more pronounced in women and individuals with BMI ranging from 24 to 28 kg/m^2. Moreover, the correlation between TyG index and diabetes risk in overweight or obese individuals increases with advancing age. Consequently, the TyG index is a reliable indicator for identifying the risk of diabetes mellitus in overweight or obese people, particularly among individuals with high-risk factors, such as being female, having a BMI between 24 and 28 kg/m^2, and being older. Based on this, clinicians can use the TyG index as a simple and reliable tool to identify populations at a high risk for diabetes and implement timely preventive measures, thereby reducing the incidence of diabetes.

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Author contributions
YS and YL contributed the central idea, YS and AL analyzed most of the data. YS wrote the initial draft of the paper. GY and YZ helped in revising the manuscript. XL, XW, YD, JZ, and FS contributed to the data collection, and Xue Lv, JZ, ZL, ZZ, Michael Zhang, YH, FL, and HL contributed to the opinion refinement, supplementary analysis, and finalization of this paper. The author(s) read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The research protocol received ethics approval from the Ethics Committee of Henan Provincial People's Hospital (Approval Code: 2021 Lunar Review No. 68). These data are a contribution of the China Health Quantitative CT Big Data Research team, registered at clinicaltrials.gov (code: NCT03699228).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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