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ORIGINAL RESEARCH

Association Between Triglyceride Glucose Index and Hypertension According to Different Diagnostic Criteria

Hua Hao, Hui Geng, Mao Ma

Physical Examination Center, the First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, Shaanxi, People's Republic of China

Correspondence: Mao Ma, Email mamaoxj@163.com

Objective: To explore the association between triglyceride glucose index (TyG) and hypertension under different diagnostic thresholds.

Methods: This study analyzed data from routine occupational health examinations conducted at the First Affiliated Hospital of Xi'an Jiaotong University in 2019. TyG and TyG-BMI, indicators of insulin resistance (IR), were calculated using triglyceride (TG), fasting blood glucose (FPG), and body mass index (BMI). Hypertension was defined by thresholds of 140/90 mmHg and 130/80 mmHg. Logistic regression models were employed to investigate the association between TyG and hypertension.

Results: Among 4028 subjects, after adjusting for covariates, the risk of hypertension (diagnosed by 140/90 mmHg) was 2.87 times higher (OR=2.87, 95% CI: 2.11–3.91) in the Q4 group of TyG compared to the Q1 group. Similarly, the risk was 8.03 times higher (OR=8.03, 95% CI: 5.05–12.75) in the Q4 group of TyG-BMI than in the Q1 group. Furthermore, the risk of hypertension (diagnosed by 130/80 mmHg) was 2.93 times higher (OR=2.93, 95% CI: 2.34–3.68) in the Q4 group of TyG compared to the Q1 group, and 7.12 times higher (OR=7.12, 95% CI: 5.08–9.99) in the Q4 group of TyG-BMI than in the Q1 group. The restricted cubic spline further showed a dose-response relationship between TyG/ TyG-BMI and hypertension. In the population with a BMI of 24.0–27.9 kg/m^2, the risk of developing hypertension (diagnosed by 140/90 mmHg) in the Q4 group of TyG was 2.79 times higher (OR=2.79, 95% CI: 1.67–4.66), while the Q4 group with TyG had a 3.07 times greater risk of hypertension (diagnosed by 130/80 mmHg) than the Q1 group (OR=3.07, 95% CI: 2.05–4.60).

Conclusion: TyG is an independent risk factor for hypertension across different thresholds, showing a clear dose-response relationship. BMI may influence this association, emphasizing the importance of managing insulin resistance early to aid hypertension prevention.

Keywords: triglyceride glucose index, hypertension, insulin resistance, body mass index

Introduction

High blood pressure, also known as hypertension, is a major preventable risk factor for cardiovascular disease (CVD) and all-cause mortality.[1–3] In 2010, a total of 1.39 billion individuals were identified as hypertensive (with systolic blood pressure (SBP)/ diastolic blood pressure (DBP)≥140/90 mmHg), representing a substantial 31.1% of the global adult population.[4] As the population ages and unhealthy lifestyles increases, including unhealthy dietary patterns with high sodium and low potassium intake and lack of physical activity, the prevalence of hypertension has been increasing globally.[4] However, the trend of hypertension is not consistent across countries, with a significant increase in the prevalence of hypertension in low - and middle-income countries over the past two decades.[1,4] Hypertension is also an important public health problem in China.[5] The China hypertension survey conducted in 2015 showed a prevalence of hypertension of 27.9% (standardized rate of 23.3%). When combined with earlier nationwide surveys, these results suggested an overall increasing trend in hypertension prevalence.[6,7] In addition, hypertension contributed to a heavy burden of disease, with a 2015 study finding that SBP ≥140mmHg was associated with more than 1.7 million deaths and

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32 million disability-adjusted life years, accounting for more than 22% of global health losses from hypertension.[8] Therefore, early identification and control of risk factors is important for hypertension prevention and control.

Insulin resistance (IR) serves as a primary indicator in most metabolic diseases, reflecting underlying pathophysiological processes related to metabolic and inflammatory states.[9,10] The triglyceride glucose index (TyG), as a simple surrogate marker for assessing IR, offers the advantages of low cost and ease of acquisition.[11,12] After adjusting body mass index (BMI), the TyG-BMI based on TyG can enhance the efficacy of IR assessment.[13,14] Both TyG and TyG-BMI have garnered increasing attention in metabolic disease research. While previous studies have explored the relationship between the TyG index and hypertension, findings have been inconsistent.[15] Furthermore, the results of the Systolic Blood Pressure Intervention Trial (SPRINT) have influenced changes in hypertension thresholds.[16] In 2017, the US lowered the hypertension threshold for the general population from 140/90 mmHg to 130/80 mmHg.[16] China had also conducted extensive research on adjusting hypertension thresholds,[17,18] yet no consensus had been reached, underscoring the need for further research evidence. There is a scarcity of studies focusing on the correlation between TyG/TyG-BMI and hypertension under different hypertension thresholds. The present study aims to address this gap by examining the impact of changing hypertension thresholds on the relationship between IR and hypertension.

This study utilized survey data from the physical examination center of the First Affiliated Hospital of Xi'an Jiaotong University to evaluate the association between TyG and hypertension based on different criteria. The findings offered a reference point for the convenient and swift identification of the relationship between IR and hypertension within the population, thereby aiding practice applications.

Methods

Study Design and Participants

Data were obtained from the routine occupational health examination (January-December 2019) of the physical examination center of the First Affiliated Hospital of Xi'an Jiaotong University, and a total of 4028 subjects were included, mainly employees of enterprises and public institutions. Inclusion criteria were ≥18 years of age, no serious illness, ability to complete the questionnaire and sign informed consent under the guidance of the investigator. The survey included questionnaires, physical examinations and blood tests. The questionnaire mainly included sociodemographic characteristics, lifestyle, disease history, mental health status, and reproductive history. The questionnaire was conducted by face-to-face interviews with trained investigators. Physical examination included height, weight, blood pressure, body composition, etc. Weight was measured by a body composition analyser (TANITA-TBF-300GS; Tanita Corporation, Tokyo, Japan). A calibrated stadiometer was used to obtain the standing height. Blood pressure was measured by uniformly purchased medical arm-type electronic sphygmomanometer (UA-779). Subjects were required to maintain emotional stability 0.5h before measurement, and the difference between the two measurements was less than 5 mmHg. The average value of the two measurements was taken as the final result. Blood samples were collected following standardized procedures by experienced nurses to prepare serum for biochemical and hematological analysis using an automatic biochemical analyzer (7600–020, Hitachi). Fasting blood glucose (FPG) was detected by oxidase method and triglyceride (TG) was detected by glycerophosphate oxidase-peroxidase method.

All operations in this study were conducted in accordance with the Declaration of Helsinki, and all subjects provided signed informed consent. This study was approved by the First Affiliated Hospital of Xi'an Jiaotong University (No. XJTU1AF2020LSK-091).

Assessment of Study Variables

Hypertension was the primary outcome variable in this study. In this study, hypertension was defined as self-reported hypertension, taking antihypertensive medication or SBP/DBP≥140/90 mmHg according to the 2018 Chinese guidelines for the management of hypertension.[19] Alternatively, it was defined as self-reported hypertension, taking antihypertensive drugs or SBP/DBP≥130/80 mmHg according to the 2017 American College of Cardiology (ACC)/ American Heart Association (AHA) guidelines.[16]

In this study, physiological and biochemical measurements such as TG and FPG were used to construct TyG index. TyG was calculated by the formula ln [TG (mg/dl) × FPG (mg/dl)/2]. A higher TyG value indicated a higher level of insulin resistance (IR). Considering the influence of BMI on TyG, this study also used TyG-BMI, which was calculated as TyG×BMI. TyG and TyG-BMI were the main independent variables, which were used as quantitative variables or categorical variables. When used as categorical variables, they were divided into four groups (Q_1, Q_2, Q_3 and Q_4), with group Q_1 serving as the reference.

Covariates

Numerous factors influence the association between TyG levels and hypertension. Based on previous literature and the findings of our study, the covariates considered in this investigation encompassed the following categories: age (≤35, 35–65, > 65 years), gender (male, female), education level (high school or below, university, postgraduate or above), marital status (married, other), annual household income (< 50,000, 50,000–100,000, ≥ 100,000 yuan), self-assessed health status (best, better, good, normal, bad), physical activity (never, occasionally, often), BMI (< 18.5, 18.5–23.9, 24–27.9, ≥28 kg/m^2), smoking habits (not smoker, ex-smoker, smoker), alcohol consumption (not drinker, occasional drinker, regular drinker). BMI was calculated by dividing weight in kilograms by the square of height in meters. Smoking and alcohol consumption were categorized based on their frequency over the past year.

Statistical Analysis

Count data were described by frequency (n) and percentage (%), and Chi-square test was used for comparison between groups. Continuous data were described by mean ± standard deviation (SD), and comparisons between groups were performed by *t*-test. Three logistic regression models were established to examine the relationship between TyG/ TyG-BMI and hypertension, estimating the odds ratio (OR) and its 95% confidence interval (CI) with TyG/ TyG-BMI modeled in quartiles. Model 1 was adjusted for age and gender, model 2 further adjusted for education level, marital status, annual household income, smoking habits and alcohol consumption based on model 1, and model 3 further adjusted for self-assessed health status, physical activity and BMI based on Model 2 (BMI was not adjusted in Model 3 for TyG-BMI). To assess the stability of the relationship between TyG/ TyG-BMI and hypertension, a linear regression model was established with TyG/TyG-BMI treated as continuous data and covariates added sequentially following the aforementioned modeling strategy. Further, the dose-response relationship between TyG/ TyG-BMI and hypertension was explored using the restricted cubic spline function (with 4 nodes: P_{25}, P_{50}, P_{75}, P_{95}). Finally, subgroup analysis was performed for each covariate, with TyG introduced as a categorical variable to investigate the stability of the TyG and hypertension relationship in each subgroup. Statistical analysis was performed using Stata 18.0, with a two-sided test at a significance level of α=0.05.

Results

Basic Information of Subjects

A total of 4028 subjects were included, of whom 2018 (50.10%) were male, with an average age of 46.78 ± 14.34 years. The average TyG level was 8.44 ± 0.63, and the average TyG-BMI was 201.36 ± 35.24. Other socio-demographic characteristics of the subjects were presented in Table 1. Using the diagnostic threshold of 140/90 mmHg, 893 (22.17%) individuals were diagnosed with hypertension. With the lower threshold of 130/80 mmHg, the number of diagnosed hypertensive individuals increased to 1786 (44.34%), marking an increase of 893 individuals. TyG and TyG-BMI levels were higher in hypertensive subjects compared to non-hypertensive subjects under both diagnostic thresholds. Other socio-demographic characteristics according to hypertension status were detailed in Table 1.

Association Between TyG/ TyG-BMI and Hypertension

After adjusting for age, gender, education level, marital status, annual household income, smoking habits, alcohol consumption, self-assessed health status, physical activity and BMI, the risk of hypertension (diagnosed using the threshold of 140/90 mmHg) was 2.87 times higher (OR=2.87, 95% CI: 2.11–3.91) in the Q4 group of TyG compared

Table 1 Sociodemographic Characteristics of Subjects According to Hypertension Status

Variables	Total (N=4028)	Hypertension by 140/90 mmHg		Hypertension by 130/80 mmHg	
		No	Yes	No	Yes
Gender					
Male	2018(50.10)	1475(47.05)	543(60.81)*	931(41.53)	1087(60.86)*
Female	2010(49.90)	1660(52.95)	350(39.19)	1311(58.47)	699(39.14)
Age(years)					
≤35	1260(31.28)	1163(37.10)	97(10.86)*	901(40.19)	359(20.10)*
35–65	2358(58.54)	1807(57.64)	551(61.70)	1244(55.49)	1114(62.37)
>65	410(10.18)	165(5.26)	245(27.44)	97(4.33)	313(17.53)
Education level					
High school or below	1393(34.58)	920(29.35)	473(52.97)*	639(28.50)	754(42.22)*
University	2159(53.60)	1791(57.13)	368(41.21)	1292(57.63)	867(48.54)
Postgraduate or above	476(11.82)	424(13.52)	52(5.82)	311(13.87)	165(9.24)
Marital status					
Married	3388(84.11)	2614(83.38)	774(86.67)*	1834(81.80)	1554(87.01)*
Others	640(15.89)	521(16.62)	119(13.33)	408(18.20)	232(12.99)
Annual household income					
<50,000	1228(30.49)	902(28.77)	326(36.51)*	636(28.37)	592(33.15)*
50,000–100,000	1511(37.51)	1159(36.97)	352(39.42)	830(37.02)	681(38.13)
≥100,000	1289(32.00)	1074(34.26)	215(24.08)	776(34.61)	513(28.72)
Alcohol consumption					
Not drinker	1589(39.45)	1231(39.27)	358(40.09)*	911(40.63)	678(37.96)*
Occasional drinker	2121(52.66)	1691(53.94)	430(48.15)	1205(53.75)	916(51.29)
Regular drinker	318(7.89)	213(6.79)	105(11.76)	126(5.62)	192(10.75)
Smoking habits					
Not smoker	3104(77.06)	2467(78.69)	637(71.33)*	1805(80.51)	1299(72.73)*
Ex-smoker	127(3.15)	87(2.78)	40(4.48)	58(2.59)	69(3.86)
Smoker	797(19.79)	581(18.53)	216(24.19)	379(16.90)	418(23.40)
Physical activity					
Never	1001(24.85)	806(25.71)	195(21.84)*	579(25.83)	422(23.63)*
Occasionally	937(23.26)	782(24.94)	155(17.36)	579(25.83)	358(20.04)
Often	2090(51.89)	1547(49.35)	543(60.81)	1084(48.35)	1006(56.33)
Self-assessed health status					
Best	192(4.77)	164(5.23)	28(3.14)*	124(5.53)	68(3.81)*
Better	823(20.43)	705(22.49)	118(13.21)	497(22.17)	326(18.25)
Good	1280(31.78)	1030(32.85)	250(28.00)	741(33.05)	539(30.18)
Normal	1608(39.92)	1159(36.97)	449(50.28)	824(36.75)	784(43.90)
Bad	125(3.10)	77(2.46)	48(5.38)	56(2.50)	69(3.86)
BMI (kg/m^2)					
<18.5	158(3.92)	149(4.75)	9(1.01)*	127(5.66)	31(1.74)*
18.5–23.9	2060 (51.14)	1762(56.20)	298(33.37)	1367(60.97)	693(38.80)
24–27.9	1381 (34.29)	974(31.07)	407(45.58)	625(27.88)	756(42.33)
≥28	429(10.65)	250(7.97)	179(20.04)	123(5.49)	306(17.13)
TyG, $\bar{x}$±s	8.44±0.63	8.35±0.60	8.77±0.60*	8.27±0.57	8.67±0.62*
TyG-BMI, $\bar{x}$±s	201.36±35.24	195.81±34.08	221.26±32.02*	189.87±31.91	216.01±33.83*

Notes: Value in the table were n (%).*P<0.05.

to the Q1 group. Similarly, the risk was 8.03 times higher (OR=8.03, 95% CI: 5.05–12.75) in the Q4 group of TyG-BMI than in the Q1 group. Furthermore, the risk of hypertension (diagnosed using the threshold of 130/80 mmHg) was 2.93 times higher (OR=2.93, 95% CI: 2.34–3.68) in the Q4 group of TyG compared to the Q1 group, and 7.12 times higher (OR=7.12, 95% CI: 5.08–9.99) in the Q4 group of TyG-BMI than in the Q1 group (Table 2).

Table 2 Association Between TyG/ TyG-BMI and Hypertension

	Model 1		Model 2		Model 3	
	OR (95% CI)	**P**	**OR (95% CI)**	**P**	**OR (95% CI)**	**P**
Hypertension by 140/90 mmHg						
TyG						
Q_1	Ref.		Ref.		Ref.	
Q_2	1.72 (1.26, 2.35)	0.001	1.68 (1.23, 2.30)	0.001	1.41 (1.02, 1.95)	0.035
Q_3	2.46 (1.82, 3.32)	<0.001	2.37 (1.75, 3.21)	<0.001	1.80 (1.32, 2.46)	<0.001
Q_4	4.42 (3.30, 5.92)	<0.001	4.25 (3.16, 5.71)	<0.001	2.87 (2.11, 3.91)	<0.001
TyG-BMI						
Q_1	Ref.		Ref.		Ref.	
Q_2	2.75 (1.92, 3.92)	<0.001	2.77 (1.93, 3.97)	<0.001	2.82 (1.91, 4.16)	<0.001
Q_3	4.38 (3.09, 6.20)	<0.001	4.29 (3.02, 6.10)	<0.001	4.30 (2.85, 6.48)	<0.001
Q_4	9.29 (6.58, 13.13)	<0.001	9.29 (6.56, 13.16)	<0.001	8.03 (5.05, 12.75)	<0.001
Hypertension by 130/80 mmHg						
TyG						
Q_1	Ref.		Ref.		Ref.	
Q_2	1.43 (1.16, 1.76)	0.001	1.41 (1.14, 1.74)	0.001	1.24 (1.00, 1.54)	0.047
Q_3	2.03 (1.65, 2.50)	<0.001	2.00 (1.62, 2.47)	<0.001	1.63 (1.31, 2.03)	<0.001
Q_4	4.04 (3.26, 5.00)	<0.001	4.01 (3.23, 4.98)	<0.001	2.93 (2.34, 3.68)	<0.001
TyG-BMI						
Q_1	Ref.		Ref.		Ref.	
Q_2	2.02 (1.62, 2.52)	<0.001	2.02 (1.61, 2.52)	<0.001	2.08 (1.64, 2.63)	<0.001
Q_3	2.97 (2.38, 3.71)	<0.001	2.94 (2.35, 3.67)	<0.001	3.25 (2.47, 4.27)	<0.001
Q_4	6.93 (5.50, 8.72)	<0.001	6.99 (5.54, 8.82)	<0.001	7.12 (5.08, 9.99)	<0.001

Notes: Logistic regression analysis was performed, with model 1 adjusted for age and gender. Model 2 further adjusted for education level, marital status, annual household income, smoking habits and alcohol consumption. Model 3 additionally adjusted for self-assessed health status, physical activity and BMI (BMI was not adjusted for in model 3 for TyG-BMI).
Abbreviations: TyG, triglyceride glucose index; BMI, body mass index.

In the linear regression analysis using TyG and TyG-BMI as continuous variables, after adjusting for all covariates, each 1-unit increase in TyG was associated with an increase of 5.17 mmHg in SBP (β=5.17, 95% CI: 4.38–5.95) and 3.08 mmHg in DBP (β=3.08, 95% CI: 2.55–3.61). Similarly, for every 1-unit increase in TyG-BMI, SBP increased by 0.17 mmHg (β=0.17, 95% CI: 0.15–0.19), and DBP increased by 0.10 mmHg (β=0.10, 95% CI: 0.08–0.11) (Table 3).

Table 3 Association Between TyG/ TyG-BMI and Blood Pressure

	Model 1		Model 2		Model 3	
	β (95% CI)	**P**	**β (95% CI)**	**P**	**β (95% CI)**	**P**
SBP						
TyG	7.03 (6.26, 7.79)	<0.001	6.95 (6.18, 7.71)	<0.001	5.17 (4.38, 5.95)	<0.001
TyG-BMI	0.16 (0.15, 0.17)	<0.001	0.16 (0.15, 0.17)	<0.001	0.17 (0.15, 0.19)	<0.001
DBP						
TyG	4.14 (3.63, 4.65)	<0.001	4.11 (3.59, 4.62)	<0.001	3.08 (2.55, 3.61)	<0.001
TyG-BMI	0.09 (0.09, 0.10)	<0.001	0.09 (0.09, 0.10)	<0.001	0.10 (0.08, 0.11)	<0.001

Notes: Linear regression analysis was conducted with TyG, TyG-BMI, and blood pressure as continuous variables. Model 1 adjusted for age and gender. Model 2 further adjusted for education level, marital status, annual household income, smoking habits and alcohol consumption. Model 3 additionally adjusted for self-assessed health status, physical activity and BMI (BMI was not adjusted for in model 3 for TyG-BMI).
Abbreviations: TyG, triglyceride glucose index; BMI, body mass index.

Association Between TyG and Hypertension in Different BMI States

TyG was not statistically associated with either threshold diagnosis of hypertension in people with BMI <18.5 kg/m^2 or BMI > 28.0 kg/m^2. However, after adjusting for covariates, among those with a BMI of 18.5–23.9 kg/m^2, the risk of hypertension (diagnosed by 140/90 mmHg) in the Q4 group of TyG was 3.10 times higher (OR=3.10, 95% CI: 1.97–4.88) than that in the Q1 group. Similarly, the Q4 group with TyG had a 3.08 times greater risk of developing hypertension (diagnosed by 130/80 mmHg) than the Q1 group (OR=3.08, 95% CI: 2.24–4.24). In the population with a BMI of 24.0–27.9 kg/m^2, the risk of developing hypertension (diagnosed by 140/90 mmHg) in the Q4 group of TyG was 2.79 times higher (OR=2.79, 95% CI: 1.67–4.66), while the Q4 group with TyG had a 3.07 times greater risk of hypertension (diagnosed by 130/80 mmHg) than the Q1 group (OR=3.07, 95% CI: 2.05–4.60) (Table 4).

Dose-Response Relationship Between TyG/ TyG-BMI and Hypertension

The dose-response relationship between TyG/TyG-BMI and hypertension was explored using restricted cubic spline plots (Figure 1). The risk of hypertension (diagnosed by 140/90 mmHg) tended to increase with increasing TyG/TyG-BMI, where the association between hypertension (diagnosed by 140/90 mmHg) and TyG-BMI was a nonlinear dose-response relationship (P for non-linear association<0.05). Additionally, the risk of hypertension diagnosed by the 130/80 mmHg threshold also increased with the increase of TyG/TyG-BMI in a linear dose-response relationship.

Subgroup Analysis

We conducted a stratified analysis to further explore the relationship between TyG index and hypertension. Subgroup analysis showed that the relationship between TyG and hypertension remained relatively stable under different diagnostic thresholds of hypertension (Table 5).

Table 4 Association Between TyG and Hypertension in Different BMI States

BMI(kg/m^2)	Hypertension by 140/90 mmHg		Hypertension by 130/80 mmHg	
	OR (95% CI)	P	OR (95% CI)	P
<18.5				
Q_1	Ref.		Ref.	
Q_2	1.72 (0.06, 53.63)	0.756	0.56 (0.16, 1.98)	0.365
Q_3	3.45 (0.10, 117.84)	0.492	0.26 (0.04, 1.71)	0.159
Q_4	0.98 (0.03, 36.33)	0.991	5.62 (0.36, 87.52)	0.218
18.5–23.9				
Q_1	Ref.		Ref.	
Q_2	1.54 (0.98, 2.42)	0.060	1.30 (0.99, 1.72)	0.060
Q_3	2.17 (1.39, 3.39)	0.001	1.82 (1.36, 2.43)	<0.001
Q_4	3.10 (1.97, 4.88)	<0.001	3.08 (2.24, 4.24)	<0.001
24.0–27.9				
Q_1	Ref.		Ref.	
Q_2	1.14 (0.65, 1.99)	0.658	1.16 (0.76, 1.78)	0.481
Q_3	1.50 (0.88, 2.54)	0.133	1.61 (1.08, 2.41)	0.020
Q_4	2.79 (1.67, 4.66)	<0.001	3.07 (2.05, 4.60)	<0.001
≥28.0				
Q_1	Ref.		Ref.	
Q_2	1.30 (0.42, 4.03)	0.646	1.08 (0.39, 2.99)	0.879
Q_3	0.99 (0.33, 2.97)	0.991	0.88 (0.33, 2.37)	0.808
Q_4	1.46 (0.50, 4.25)	0.485	1.58 (0.60, 4.13)	0.353

Notes: Logistic regression analysis was performed with age, gender, education level, marital status, annual household income, smoking habits, alcohol consumption, self-assessed health status, physical activity and BMI were adjusted.

Abbreviations: TyG, triglyceride glucose index; BMI, body mass index.

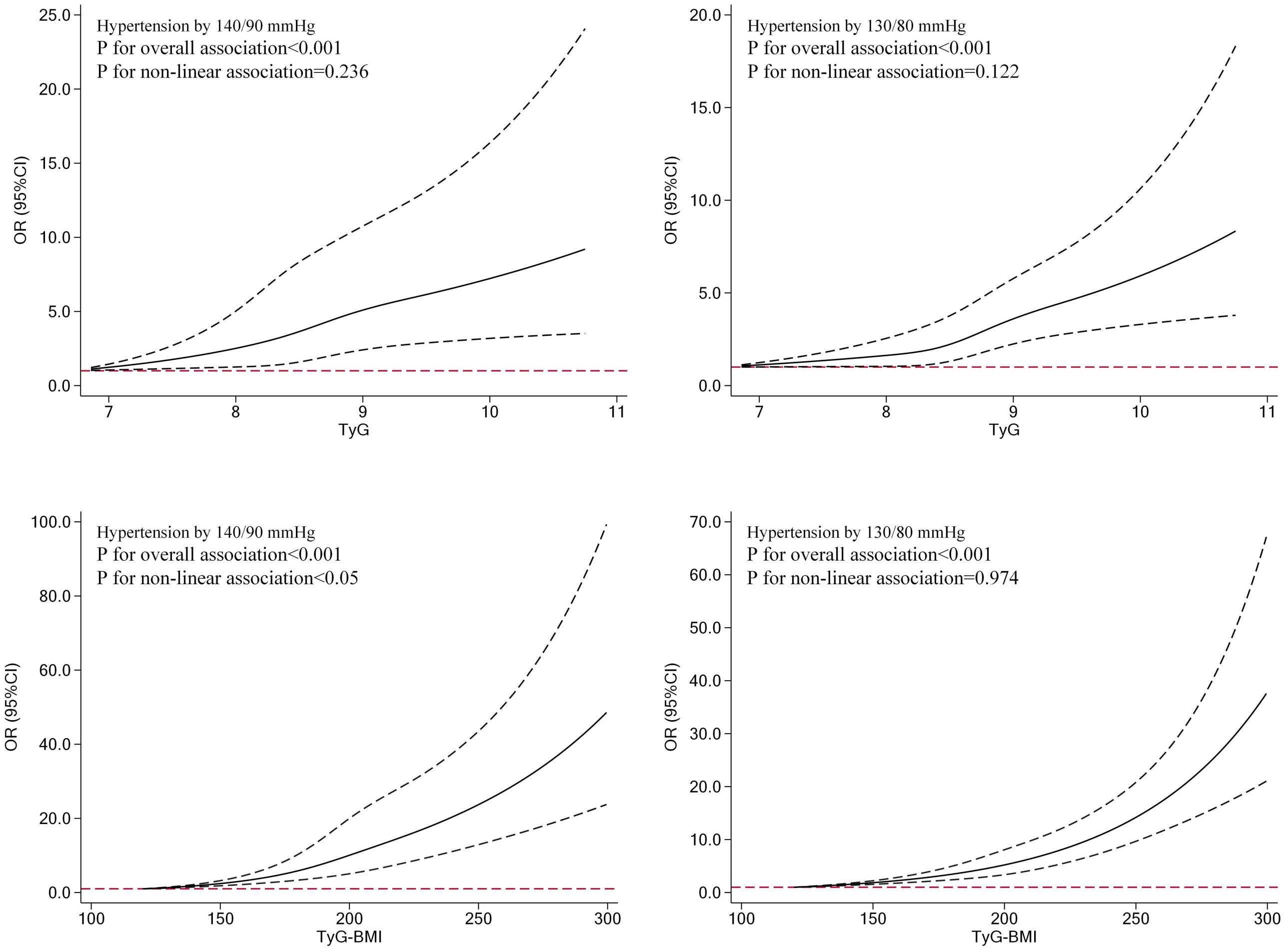

Figure 1 Dose-response relationship between TyG/ TyG-BMI and hypertension. Age, gender, education level, marital status, annual household income, smoking habits, alcohol consumption, self-assessed health status, physical activity and BMI were adjusted (BMI was not adjusted for TyG-BMI). The dotted lines were 95% CI.
Abbreviations: TyG, triglyceride glucose index; BMI, body mass index.

Discussion

This study found that both TyG and TyG-BMI were significantly and independently positively correlated with hypertension, exhibiting a dose-response relationship. The association of TyG-BMI with hypertension was stronger. Subgroup analysis further confirmed the stability of the associations of TyG and TyG-BMI with hypertension. BMI may modulate the relationship between TyG and hypertension. Higher TyG levels were associated with a greater risk of hypertension in populations of normal weight and overweight, with the association appearing more significant in normal weight populations. However, no significant associations were found in underweight and obese populations.

Hyperinsulinaemic-euglycaemic clamp is the gold standard to evaluate IR, but this method is complicated and expensive, making it difficult to be widely used in large-scale investigation. TyG, which combines FPG and TG, has been proposed in recent years to be simple to calculate and easy to measure, and has been proven to be used as an effective alternative indicator of IR.[20,21] Studies focusing on TyG/TyG-BMI, as long as the main focus is on the relationship with cardiovascular disease, diabetes and all-cause mortality.[22–24] Few studies have explored the relationship between TyG and hypertension. Using longitudinal data from the China Health and Nutrition Survey (2009–2015), Gao et al found that a high TyG index was significantly associated with new-onset hypertension in Chinese adults.[25] Using data from the Korea National Health and Nutrition Examination Survey (2016–2019), Dong et al found that both systolic and diastolic blood pressure, along with the prevalence of hypertension, increased with rising TyG indices.[26] Chen et al used the data of the China Health and Retirement Longitudinal Study to explore the relationship between TyG and the risk of hypertension in middle-aged and elderly people in China with different waist circumference, and found that TyG

Table 5 Subgroup Analysis of Association Between TyG and Hypertension

Subgroup	Hypertension by 140/90 mmHg		Hypertension by 130/80 mmHg	
	OR (95% CI)	P	OR (95% CI)	P
Gender				
Male	1.53 (1.28, 1.83)	<0.001	1.80 (1.51, 2.14)	<0.001
Female	2.16 (1.69, 2.78)	<0.001	2.07 (1.70, 2.52)	<0.001
Age(years)				
≤35	1.89 (1.26, 2.81)	0.002	1.52 (1.16, 1.98)	0.002
35–65	1.66 (1.40, 1.98)	<0.001	2.02 (1.72, 2.37)	<0.001
>65	1.73 (1.16, 2.60)	0.008	2.08 (1.29, 3.35)	0.003
Education level				
High school or below	1.78 (1.42, 2.23)	<0.001	1.85 (1.49, 2.30)	<0.001
University	1.80 (1.46, 2.22)	<0.001	2.07 (1.73, 2.48)	<0.001
Postgraduate or above	1.33 (0.77, 2.32)	0.309	1.65 (1.11, 2.46)	0.013
Marital status				
Married	1.73 (1.48, 2.02)	<0.001	1.96 (1.71, 2.25)	<0.001
Others	2.31 (1.44, 3.69)	<0.001	2.04 (1.38, 3.02)	<0.001
Annual household income				
<50,000	1.76 (1.38, 2.24)	<0.001	2.20 (1.74, 2.78)	<0.001
50,000–100,000	1.84 (1.45, 2.33)	<0.001	1.99 (1.62, 2.45)	<0.001
≥100,000	1.74 (1.30, 2.33)	<0.001	1.73 (1.37, 2.19)	<0.001
Alcohol consumption				
Not drinker	2.13 (1.65, 2.75)	<0.001	2.52 (2.02, 3.16)	<0.001
Occasional drinker	1.51 (1.25, 1.84)	<0.001	1.66 (1.40, 1.96)	<0.001
Regular drinker	2.43 (1.49, 3.96)	<0.001	1.99 (1.27, 3.12)	0.003
Smoking habits				
Not smoker	1.88 (1.58, 2.25)	<0.001	2.10 (1.80, 2.44)	<0.001
Ex-smoker	1.17 (0.57, 2.44)	0.666	2.31 (1.11, 4.80)	0.025
Smoker	1.53 (1.15, 2.04)	0.003	1.43 (0.86, 2.39)	0.173
Physical activity				
Never	1.38 (1.02, 1.88)	0.039	1.75 (1.35, 2.28)	<0.001
Occasionally	1.58 (1.13, 2.22)	0.008	2.08 (1.57, 2.75)	<0.001
Often	2.04 (1.68, 2.48)	<0.001	1.99 (1.67, 2.38)	<0.001
Self-assessed health status				
Best	1.47 (0.61, 3.52)	0.392	2.42 (1.25, 4.71)	0.009
Better	1.59 (1.09, 2.33)	0.017	1.64 (1.22, 2.20)	0.001
Good	1.74 (1.33, 2.26)	<0.001	1.88 (1.50, 2.35)	<0.001
Normal	1.96 (1.57, 2.43)	<0.001	2.22 (1.80, 2.73)	<0.001
Bad	2.44 (1.08, 5.49)	0.031	3.57 (1.49, 8.57)	0.004
BMI (kg/m^2)				
<18.5	1.92 (0.22, 16.62)	0.553	1.42 (0.48, 4.16)	0.528
18.5–23.9	1.97 (1.54, 2.53)	<0.001	1.99 (1.65, 2.41)	<0.001
24–27.9	1.85 (1.49, 2.28)	<0.001	2.11 (1.72, 2.59)	<0.001
≥28	1.17 (0.80, 1.72)	0.414	1.51 (1.00, 2.26)	0.047

Notes: In each subgroup, variables other than the subgroup variables were adjusted. TyG was included in the analysis as a continuous variable.
Abbreviations: TyG, triglyceride glucose index; BMI, body mass index.

was positively correlated with the risk of hypertension in people with central obesity prophase.[27] These findings were consistent with the present study, which found that hypertension diagnosed under different thresholds was associated with TyG, suggesting that changes in the threshold of hypertension did not affect the association. The association between TyG-BMI and hypertension is stronger than that between TyG and hypertension. BMI, a simple and readily available measure of overall obesity, when combined with TyG, more effectively predicts adverse cardiovascular events.[28] The association between TyG and hypertension can be explained by IR, and previous studies have confirmed that IR affects hypertension through multiple mechanisms. IR may stimulate sympathetic nervous system activity, induce the secretion of epinephrine and norepinephrine, and lead to increased cardiac output and peripheral vascular resistance through vascular smooth muscle cell hypertrophy and endothelial dysfunction.[29,30] IR may also induce hypertension by stimulating the synthesis of vascular endothelin, thereby constricting blood vessels and inhibiting vasodilation response.[31] In addition, as two components of TyG, TC and FPG are closely related to the occurrence of hypertension.[32,33] More mechanistic studies are needed to further validate the relationship between TyG index, IR, and hypertension.

The results of this study show that IR was positively associated with hypertension in individuals with normal BMI as well as in overweight individuals. This suggested that early prevention of elevated IR levels, even before overweight or obesity, may positively impact hypertension control. Previous studies had elucidated the underlying mechanism of the association between obesity and IR, emphasizing IR's crucial role in both hypertension and secondary hyperinsulinemia associated weight gain.[34] In the current study, we employed two indicators, TyG and TyG-BMI, to assess the association between IR and hypertension. These indicators were cost-effective and easy to obtain, offering high utility in population studies and providing a reference for the easy and rapid identification of the IR-hypertension relationship in the population in practice.

To the best of our knowledge, this study is the first to reveal the association between TyG and hypertension at various thresholds in the general population. The study also has limitations. First, this study was a cross-sectional study, and we could not accurately determine the causal relationship between TyG and hypertension. Second, recall bias in the collection of some covariates using questionnaires was difficult to avoid. Third, in the subgroup analysis, due to the limited sample size, the reduced sample size in the stratified population analyses might not allow for an accurate evaluation of each subgroup's effects, but TyG and hypertension in most subgroups were in the same direction and significant, indicating a stable relationship. Fourth, the relationship between TyG and hypertension may be underestimated or overestimated without considering potential confounding factors such as diet and taking different anti-hypertensive drugs. Finally, the study lacked investigations into the biological mechanisms, and future randomized controlled trials were necessary to verify the causal association between TyG and hypertension.

Conclusion

TyG is an independent risk factor for hypertension, with a dose-response relationship between the two. BMI may modulate this relationship, and early prevention of elevated IR levels in overweight or obese individuals could positively impact hypertension control. TyG-BMI has a higher value in identifying hypertension compared to TyG alone. Our findings suggest that TyG holds significant clinical implications for the early improvement of hypertension management.

Data Sharing Statement

Data used and/or analyzed during the study are available upon reasonable request from the corresponding author.

Ethics Approval and Consent to Participate

The current study adhered to the Declaration of Helsinki guidelines. Participants provided signed informed consent forms before undergoing questioning and physical examinations, following a protocol approved by the Ethics Committee of the First Affiliated Hospital of Xi'an Jiaotong University (No. KYLLSL-2020-156).

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Disclosure

The authors report no conflicts of interest in this work.

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