Association Between The Triglyceride-Glucose (TyG) Index and Increased Blood Pressure in Normotensive Subjects: A Population-Based Study

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Abstract

Insulin resistance (IR) is an important contributor to the development of hypertension (HTN), and the triglyceride-glucose (TyG) index has been proposed as a simple, reliable marker of IR. This study investigated the association between the TyG index and blood pressure (BP) elevation in a large general population without a history of related diseases. The study enrolled 15,826 adults from the 2016–2019 Korea National Health and Nutrition Examination Survey (KNHANES). Participants were classified into quartiles based on the TyG index and BP was categorized as normal BP, elevated BP, pre-HTN, and HTN. The associations of the TyG index with BP categories were assessed using multivariate multinomial logistic regression models with normal BP as the reference group. The mean systolic/diastolic BP and prevalence of HTN increased with the TyG index. The continuous TyG index had a strong dose-response relationship with increased odds of elevated BP, pre-HTN, and HTN. Compared with the lowest TyG index quartile, the highest TyG index quartile was significantly associated with higher odds of having elevated BP (OR, 1.52; 95% CI, 1.23–1.87), pre-HTN (OR, 2.18; 95% CI, 1.91–2.48), and HTN (OR, 4.14; 95% CI, 3.40–5.02). Our study suggests that the TyG index is an early predictor of the risk of HTN.

Introduction

Hypertension (HTN) is an important public health problem because of its increasing prevalence and association with complications such as cardiovascular disease (CVD)[1]. According to the Korea Hypertension Fact Sheet 2020, the number of people with HTN increased from 3.0 million in 2002 to 9.7 million in 2018[2]. Considering the impact of HTN on morbidity and mortality, there is a need for early predictors of incident HTN, especially in healthy individuals.

Insulin resistance (IR) is an important contributor to the development of HTN[3,4]. Recently, the triglyceride-glucose (TyG) index, which is calculated using fasting triglycerides and plasma glucose (FPG), was suggested to be a reliable surrogate marker for IR[5,6]. Several studies demonstrated that the TyG index is correlated with the homeostasis model assessment of insulin resistance (HOMA-IR) and better predicted IR than the HOMA-IR in some studies[5,7–9]. Therefore, many studies have evaluated the TyG index as a predictor of diseases associated with IR, such as type 2 diabetes, metabolic syndrome, non-alcoholic fatty liver disease, and CVD[10–13]. Studies have demonstrated an association between the TyG index and HTN[14–16], albeit in different study populations.

No study has examined whether the TyG index can predict the risk of HTN in apparently healthy individuals. Therefore, this study evaluated the association between the quartiles of the TyG index and risk of HTN, using data from the Korea National Health and Nutrition Examination Survey (KNHANES).

Methods

Data sources and study population

The study data were from the 7th (2016–2018) and 8th (2019) KNHANES conducted by the Korea Disease Control and Prevention Agency (KDCA). The KNHANES is a nationally representative cross-sectional survey that assesses the health and nutritional status of Koreans and monitors trends in health risk factors and the prevalence of major chronic diseases[17].

Of 25,995 adults aged 19 and over in the 2016–2019 KNHANES database, blood glucose and triglycerides levels measured after a fast of at least 8 hours were available for 23,292 participants. We also excluded participants whose blood pressure (BP) was not recorded (n = 76), who had been previously diagnosed with HTN, myocardial infarction, stroke, or angina (n = 6,062), or who were taking diabetes medications (oral antihyperglycemic agents and insulins) or antihyperlipidemic agents (n = 1,328). Finally, 15,826 participants with complete information were included in our analysis and categorized according to the quartiles of the TyG index (Q1-Q4).

Laboratory assessment and anthropometric measurements

Blood samples for biochemical tests were collected at a mobile examination center and analyzed using a Hitachi Automatic Analyzer 7600 – 210 or Labospect 008 AS (Hitachi, Tokyo, Japan). FPG was measured by the hexokinase UV method; triglycerides and total cholesterol were measured by enzymatic methods; and high-density lipoprotein (HDL) cholesterol was measured using the homogeneous enzymatic colorimetric method. Low-density lipoprotein (LDL) cholesterol was measured directly (for the participants with triglycerides > 200) or calculated using the Friedewald equation as total cholesterol – HDL-cholesterol – (triglycerides/5) (mg/dL). Aspartate and alanine aminotransferase levels were measured using the International Federation of Clinical Chemistry and Laboratory Medicine UV method without pyridoxal-5-phosphate (P5P). The TyG index was calculated as ln(fasting triglycerides [mg/dL] × fasting glucose [mg/dL]/2), and classified into quartiles to investigate the association between the TyG index and BP.

Systolic (SBP) and diastolic (DBP) blood pressure were measured three times by trained nurses with a mercury sphygmomanometer (Baumanometer Wall Unit 33 [0850], W.A. Baum, NY, USA), at 5-minute intervals in a sitting position after a 5-minute rest. The average of the second and third measurements was used in the analysis. BP categories are based on the classification recommended by the Korean Society of Hypertension[18], and were classified as normal (SBP < 120 mmHg and DBP < 80 mmHg), elevated (SBP 120–129 mmHg and DBP < 80 mmHg), pre-HTN (SBP 130–139 mmHg or DBP 80–89 mmHg), and HTN (SBP ≥ 140 mmHg or DBP ≥ 90 mmHg).

All anthropometric measurements were made by trained examiners using standardized methods. Height and weight were measured with light clothes and without shoes. Body mass index (BMI), calculated by dividing weight by height squared (kg/m^2), was divided into four categories according to Asian-Pacific guidelines: < 18.5, 18.5–22.9, 23.0–24.9, and ≥ 25.0 kg/m^2[19].

Assessing sociodemographic and lifestyle variables

The participants' sociodemographic characteristics included age, sex, marital status, education level, and household income (quartiles). Participants were also asked about their smoking status (non-, former, or current-smoker) and frequency of binge drinking (abstainer, not at all, once or less than once a month, once a week, and every day). Binge drinking was defined as consuming seven or more drinks on a single occasion for men, or five or more drinks on a single occasion for women.

Statistical Analyses

Differences in general characteristics between quartile groups of the TyG index were assessed using the chi-square test for categorical variables and analysis of variance (ANOVA) with Dunnett's *post-hoc* analysis for continuous variables. Average SBP and DBP according to the quartile of the TyG index were compared using a general linear model (GLM) after adjusting for survey year, age, and sex. After checking for multicollinearity among the independent variables, multiple linear regression analysis with stepwise selection was performed to identify the combination of risk factors that best explained the variance in BP. We chose the list of correlates considered for introduction in this analysis based on the literature and whether they had a p-value < 0.05 in the unadjusted analysis. The following 13 variables were considered in the stepwise regression analysis: age, sex, marital status, education level, household income, smoking, alcohol drinking, BMI, FPG, triglycerides, total cholesterol, HDL-cholesterol, and the TyG index.

The associations between the TyG index and prevalence of elevated BP, pre-HTN, and HTN were assessed using multinomial logistic regression with normal BP as the reference group. The final multivariate-adjusted model included potential risk factors derived from the stepwise multiple regression. Participants were assigned the median value for each category to test for trends across each quartile of the TyG index, and this variable was treated as a continuous term in the model. To evaluate the potential for effect modification of TyG index quartiles and BP categories (elevated BP, pre-HTN, or HTN), we stratified the analyses by age (< 50 and ≥ 50 years), sex, and BMI (< 25 and ≥ 25 kg/m^2). A cross-product interaction term was included in the multinomial logistic regression model and the statistical significance of the interactions was assessed using the Wald test. All statistical analyses were performed using SAS ver. 9.4 (SAS Institute, Cary, NC, USA).

Ethics statement

The study design, protocols, and data release for the KNHANES was approved by the Institutional Review Board (IRB) of the KDCA (2018-01-03-P-A and 2018-01-03-C-A), and some periods were conducted without IRB approval as research conducted directly by the government for the public welfare according to the Bioethics and Safety Act of Korea[20]. Written informed consent was obtained from all participants, and all methods were performed in accordance with the relevant guidelines and regulations.

Results

Baseline characteristics

The analysis included 15,826 eligible subjects (6,825 males, 9,001 females). Table 1 presents the baseline characteristics of the subjects according to the TyG index quartiles. Compared with participants in the lowest TyG quartile, individuals in higher quartiles tend to be older, male, more prone to obesity, less educated, earn less, and have more bad habits, such as current smoking and heavy alcohol consumption (all $p < 0.001$). Furthermore, laboratory findings, including the FPG, lipid parameters, and liver function, also differed significantly among the TyG index quartiles (all $p < 0.001$). Dunnett's *post-hoc* test revealed that subjects in the second to fourth quartiles of the TyG index had significantly higher laboratory findings than those in the lowest quartile.

Table 1
Comparison of characteristics according to the quartile of TyG index (N = 15,826)

Variables	**Quartile of TyG index**				***p* value**
	Q1 (n = 3,955)	**Q2 (n = 3,958)**	**Q3 (n = 3,956)**	**Q4 (n = 3,957)**	
TyG index	7.76 ± 0.23	8.27 ± 0.12	8.68 ± 0.13	9.38 ± 0.42	
Survey year, n (%)					0.310
2016	955 (24.2)	942 (23.8)	972 (24.6)	1,025 (25.9)	
2017	988 (25.0)	1,004 (25.4)	1,030 (26.0)	949 (24.0)	
2018	987 (25.0)	1,026 (25.9)	974 (24.6)	1,003 (25.4)	
2019	1,025 (25.9)	986 (24.9)	980 (24.8)	980 (24.8)	
Age (years)	40.0 ± 14.6	44.4 ± 15.1*	47.4 ± 14.9*	47.9 ± 13.9*	< 0.001
19–29	1,127 (28.5)	726 (18.3)	518 (13.1)	355 (9.0)	< 0.001
30–39	992 (25.1)	909 (23.0)	781 (19.7)	834 (21.1)	
40–49	891 (22.5)	905 (22.9)	933 (23.6)	1,062 (26.8)	
50–64	663 (16.8)	981 (24.8)	1,153 (29.2)	1,196 (30.2)	
≥ 65	282 (7.1)	437 (11.0)	571 (14.4)	510 (12.9)	
Sex, n (%)					< 0.001
Male	998 (25.2)	1,432 (36.2)	1,901 (48.1)	2,494 (63.0)	
Female	2,957 (74.8)	2,526 (63.8)	2,055 (52.0)	1,463 (37.0)	

Abbreviation: TyG, triglyceride and glucose; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; AST, aspartate transaminase; ALT, alanine aminotransferase.

Data are expressed as the means ± SD, or n (%).

p values were generated by one-way ANOVA or chi-square test.

*represents values significantly different (p [illegible] 0.05) from control group (the lowest TyG quartile) by the one-way ANOVA followed by the Dunnett's *post-hoc* analysis.

Variables	Quartile of TyG index				*p* value
	Q1 (n = 3,955)	Q2 (n = 3,958)	Q3 (n = 3,956)	Q4 (n = 3,957)	
BMI (kg/m^2)	21.8 ± 2.9	22.8 ± 3.2*	24.0 ± 3.4*	25.4 ± 3.6*	< 0.001
< 18.5	372 (9.4)	250 (6.3)	110 (2.8)	36 (0.9)	< 0.001
18.5–22.9	2,427 (61.5)	2,032 (51.4)	1,524 (38.6)	932 (23.6)	
23.0–24.9	649 (16.4)	822 (20.8)	1,053 (25.4)	985 (24.9)	
≥ 25.0	499 (12.6)	847 (21.4)	1,313 (33.2)	1,998 (50.6)	
SBP (mmHg)	109.1 ± 13.0	113.1 ± 14.5*	117.1 ± 14.9*	121.3 ± 15.3*	< 0.001
DBP (mmHg)	71.7 ± 8.5	74.0 ± 9.2*	76.5 ± 9.3*	80.0 ± 10.1*	< 0.001
FPG (mg/dL)	88.9 ± 7.6	92.8 ± 8.1*	96.1 ± 10.9*	106.0 ± 28*	< 0.001
Total cholesterol (mg/dL)	182.7 ± 31.3	193.2 ± 32.2*	203.0 ± 33.5*	214.9 ± 37.4*	< 0.001
Triglycerides (mg/dL)	54.0 ± 11.4	85.0 ± 11.7*	124.9 ± 19.5*	250.5 ± 146.7*	< 0.001
HDL-cholesterol (mg/dL)	60.5 ± 12.3	55.5 ± 11.8*	50.9 ± 11.3*	44.5 ± 10.1*	< 0.001
LDL-cholesterol (mg/dL)	111.4 ± 27.6	120.7 ± 29.5*	127.1 ± 31.6*	127.1 ± 33.9*	< 0.001
AST (IU/L)	19.9 ± 9.2	20.9 ± 9.6*	22.3 ± 9.9*	26.6 ± 19.5*	< 0.001
ALT (IU/L)	15.5 ± 11.0	18.0 ± 13.2*	22.2 ± 18.3*	31.0 ± 26.1*	< 0.001

Abbreviation: TyG, triglyceride and glucose; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; AST, aspartate transaminase; ALT, alanine aminotransferase.

Data are expressed as the means ± SD, or n (%).

p values were generated by one-way ANOVA or chi-square test.

*represents values significantly different (p<0.05) from control group (the lowest TyG quartile) by the one-way ANOVA followed by the Dunnett's *post-hoc* analysis.

Variables	Quartile of TyG index				*p* value
	Q1 (n = 3,955)	Q2 (n = 3,958)	Q3 (n = 3,956)	Q4 (n = 3,957)	
Marital status, n (%)					< 0.001
Married	2,402 (60.8)	2,683 (67.8)	2,832 (71.6)	2,888 (73.0)	
Widowed, separated, or divorced	263 (6.7)	325 (8.2)	370 (9.4)	390 (9.9)	
Single	1,289 (32.6)	949 (24.0)	753 (19.0)	677 (17.1)	
Education level, n (%)					< 0.001
Elementary school graduate or less	254 (6.4)	352 (8.9)	425 (10.7)	458 (11.6)	
Middle school graduate	191 (4.8)	251 (6.3)	314 (7.9)	303 (7.7)	
High school graduate	1343 (34.0)	1,384 (35.0)	1,320 (33.4)	1,328 (33.6)	
College graduate or more	2,022 (51.1)	1,796 (45.4)	1,725 (43.6)	1,648 (41.7)	
Unknown	145 (3.7)	175 (4.4)	172 (4.4)	220 (5.6)	
Household income quartiles, n(%)					< 0.001
Q1 (poorest)	399 (10.1)	474 (12.0)	484 (12.3)	545 (13.8)	
Q2	916 (23.2)	920 (23.3)	955 (24.2)	963 (24.4)	
Q3	1,155 (29.3)	1,208 (30.6)	1,195 (30.3)	1,211 (30.7)	
Q4 (richest)	1,471 (37.3)	1,346 (34.1)	1,307 (33.2)	1,227 (31.1)	

Abbreviation: TyG, triglyceride and glucose; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; AST, aspartate transaminase; ALT, alanine aminotransferase.

Data are expressed as the means ± SD, or n (%).

p values were generated by one-way ANOVA or chi-square test.

*represents values significantly different ($p < 0.05$) from control group (the lowest TyG quartile) by the one-way ANOVA followed by the Dunnett's *post-hoc* analysis.

Variables	Quartile of TyG index				*p* value
	Q1 (n = 3,955)	Q2 (n = 3,958)	Q3 (n = 3,956)	Q4 (n = 3,957)	
Smoking status, n(%)					< 0.001
Non-smoker	3,102 (78.9)	2,726 (69.6)	2,378 (60.7)	1,763 (45.1)	
Former smoker	427 (10.9)	592 (15.1)	730 (18.6)	913 (23.3)	
Current smoker	401 (10.2)	598 (15.3)	809 (20.7)	1,237 (31.6)	
Frequency of binge drinking, n(%)					< 0.001
Abstainer	793 (20.2)	892 (22.8)	899 (22.9)	746 (19.1)	
Not at all	1,990 (50.6)	1,845 (47.1)	1,629 (41.6)	1,392 (35.6)	
Once or less than once a month	632 (16.1)	566 (14.5)	572 (14.6)	584 (14.9)	
Once a week	418 (10.6)	473 (12.1)	592 (15.1)	826 (21.1)	
Every day	98 (2.5)	142 (3.6)	227 (5.8)	365 (9.3)	

Abbreviation: TyG, triglyceride and glucose; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; HDL, high-density lipoprotein; LDL, low-density lipoprotein; AST, aspartate transaminase; ALT, alanine aminotransferase.

Data are expressed as the means ± SD, or n (%).

p values were generated by one-way ANOVA or chi-square test.

*represents values significantly different (p<0.05) from control group (the lowest TyG quartile) by the one-way ANOVA followed by the Dunnett's *post-hoc* analysis.

Distribution of BP and prevalence of elevated BP, pre-HTN, and HTN according to TyG index quartiles

The distribution of BP according to the quartile of TyG index is shown in Fig. 1A and 1B. SBP and DBP differed significantly among the TyG index quartiles, and had the lowest values in the lowest TyG index quartile (all $p < 0.001$). Both SBP and DBP increased with the TyG index (all p for trend < 0.001).

Figure 1C shows the percentage distribution of BP categories according to the TyG index quartile. The percentage of participants defined as HTN was highest in the highest TyG quartile and lowest in the lowest TyG quartile (21.3% *vs*. 4.1%, $p < 0.001$ among groups). The percentage increased with the TyG index quartile. Similar trends were observed for the participants classified as pre-HTN (32.8% *vs*. 14.8%).

Independent correlates of blood pressure variability

Table 2 shows the results of multiple regression analysis with stepwise variable selection to identify the aggregate combination of correlates making the greatest contribution to BP changes. Stepwise linear regression revealed that among the 13 entered variables, the most important correlates of SBP were the combination of age, sex, marital status, education level, household income, smoking status, frequency of binge drinking, BMI, FPG, HDL-cholesterol, and TyG index, accounting for 26.35% of the SBP variance in this population ($F = 510.06$, $p < 0.001$). Age, sex, household income, smoking status, frequency of binge drinking, BMI, FPG, total cholesterol, HDL-cholesterol, and the TyG index independently affected DBP, explaining 19.78% of the variance in DBP ($F = 386.95$, $p < 0.001$). Higher age, BMI and TyG index, and male sex had greater correlations with BP variability.

Table 2
Results of stepwise multiple regression analysis for predictors of BP variability

Variables	**SBP**			**DBP**		
	β	**t**	***p* value**	**β**	**t**	***p* value**
Constant		21.65	< 0.001		18.88	< 0.001
Age	0.346	41.68	< 0.001	0.077	9.77	< 0.001
Sex (1, male; 0, female)	0.145	17.83	< 0.001	0.152	17.98	< 0.001
Marital status (1, married; 0, any others)	-0.092	-12.06	< 0.001	Not entered		
Education level (1, college graduate or more; 0, any others)	-0.074	-9.95	< 0.001	Not entered		
Household income quartiles (1, Q3-Q4; 0, Q1-Q2)	-0.026	-3.54	< 0.001	0.024	3.33	< 0.001
Smoking status (1, current smoker; 0, former smoker or non-smoker)	-0.043	-5.52	< 0.001	-0.033	-4.02	< 0.001
Frequency of binge drinking	0.084	10.68	< 0.001	0.125	15.19	< 0.001
BMI (kg/m^2)	0.196	25.76	< 0.001	0.209	25.96	< 0.001
FPG (mg/dL)	0.041	5.25	< 0.001	0.027	3.34	< 0.001
Triglycerides (mg/dL)	Not entered			Not entered		
Total cholesterol (mg/dL)	Not entered			0.067	7.71	< 0.001
HDL-cholesterol (mg/dL)	0.090	10.72	< 0.001	0.068	7.06	< 0.001
TyG index	0.145	15.72	< 0.001	0.173	16.18	< 0.001

Abbreviation: SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; FPG, fasting plasma glucose; HDL, high-density lipoprotein; TyG, triglyceride and glucose.

The selection of model variables used a “stepwise” option with variable selection criteria: “slentry” = 0.05, “slstay” = 0.1.

All Betas are standardized coefficients.

Variables	SBP			DBP		
	β	**t**	***p* value**	**β**	**t**	***p* value**
Adjusted R^2	0.2635	(F = 510.06, $p < 0.001$)		0.1978	(F = 386.95, $p < 0.001$)	
Abbreviation: SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; FPG, fasting plasma glucose; HDL, high-density lipoprotein; TyG, triglyceride and glucose.						
The selection of model variables used a “stepwise” option with variable selection criteria: “slentry” = 0.05, “slstay” = 0.1.						
All Betas are standardized coefficients.						

Association of TyG index with elevated BP, pre-HTN and HTN

We used multinomial logistic regression analysis to evaluate the association of the TyG index with the prevalence of elevated BP, pre-HTN, and HTN (Table 3). The ORs of elevated BP, pre-HTN, and HTN increased with the TyG index quartiles (all *p* for trend < 0.001). Specifically, participants in the highest TyG index quartile had 1.81-fold higher odds of elevated BP (95% CI, 1.49–2.20), 2.90-fold higher odds of pre-HTN (95% CI, 2.57–3.27), and 6.33-fold higher odds of HTN (95% CI, 5.26–7.61) than the lowest TyG index quartile group in the age- and sex-adjusted model. Even after adjusting for conventional risk factors of HTN, such as demographic factors, health behavior (smoking and alcohol drinking), and BMI, participants in the highest TyG index quartile were most prominently associated with higher prevalence of elevated BP (OR, 1.52; 95% CI, 1.23–1.87), pre-HTN (OR, 2.18; 95% CI, 1.91–2.48), and HTN (OR, 4.14; 95% CI, 3.40–5.02). We also observed significant dose–response relationships between the continuous TyG index and BP categories.

Table 3
Results of multinomial logistic regression model for elevated blood pressure, pre-hypertension, and hypertension

Variables	**Continuous TyG index**	**Quartile of TyG index**				***p* trend**
		Q1	**Q2**	**Q3**	**Q4**	
Elevated BP						
No. of cases	1061	210	249	307	295	
Model 1: AOR (95% CI)	1.49 (1.33–1.66)	1.00 (ref.)	1.09 (0.89–1.32)	1.45 (1.20–1.76)	1.81 (1.49–2.20)	< 0.001
Model 2: AOR (95% CI)	1.30 (1.16–1.46)	1.00 (ref.)	1.03 (0.85–1.26)	1.29 (1.06–1.27)	1.46 (1.20–1.80)	< 0.001
Model 3: AOR (95% CI)	1.34 (1.19–1.50)	1.00 (ref.)	1.05 (0.86–1.28)	1.33 (1.09–1.61)	1.52 (1.23–1.87)	< 0.001
Pre-HTN						
No. of cases	3760	585	779	1,100	1,296	
Model 1: AOR (95% CI)	1.97 (1.84–2.11)	1.00 (ref.)	1.30 (1.15–1.47)	2.02 (1.80–2.28)	2.90 (2.57–3.27)	< 0.001
Model 2: AOR (95% CI)	1.68 (1.57–1.80)	1.00 (ref.)	1.22 (1.07–1.38)	1.74 (1.54–1.96)	2.23 (1.96–2.53)	< 0.001
Model 3: AOR (95% CI)	1.66 (1.55–1.79)	1.00 (ref.)	1.22 (1.08–1.38)	1.72 (1.52–1.95)	2.18 (1.91–2.48)	< 0.001
HTN						
No. of cases	1845	163	342	496	844	
Model 1: AOR (95% CI)	2.91 (2.67–3.17)	1.00 (ref.)	1.92 (1.57–2.34)	2.98 (2.46–3.60)	6.33 (5.26–7.61)	< 0.001
Model 2: AOR (95% CI)	2.35 (2.15–2.57)	1.00 (ref.)	1.73 (1.42–2.11)	2.38 (1.96–2.89)	4.34 (3.58–5.26)	< 0.001
Model 3: AOR (95% CI)	2.27 (2.07–2.49)	1.00 (ref.)	1.74 (1.43–2.13)	2.33 (1.92–2.84)	4.14 (3.40–5.02)	< 0.001

Abbreviation: TyG, triglyceride and glucose; BP, blood pressure; HTN, hypertension; AOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index.

Model 1: adjusted for survey year, age, and sex.

Model 2: Model 1 + BMI.

Model 3: Model 2 + marital status, education level, household income quartiles, smoking status, and frequency of binge drinking.

In the analyses stratified by age, sex, and BMI (Table 4), age significantly modified the association between the TyG index and the prevalence of pre-HTN (p interaction < 0.001) or HTN (p interaction < 0.001), and the associations were more apparent among those who were < 50 years of age. However, the association of the TyG index with BP categories did not differ by sex, except for elevated BP; elevated BP was more prominent in women than in men (p interaction = 0.015). There were also no interactions between the TyG index and BMI.

Table 4

Multivariate odds ratio (ORs) and 95% confidence intervals (CIs) for elevated blood pressure, pre-hypertension, and hypertension in relation to the quartile of TyG index by age, sex, and BMI

Variables		**Quartile of TyG index**				***p* interaction**
		Q1	**Q2**	**Q3**	**Q4**	
By age						
Elevated BP						0.471
Age < 50 years	No. of cases	111	90	101	106	
	AOR (95% CI)	1.00 (ref.)	0.88 (0.66–1.18)	1.10 (0.82–1.48)	1.26 (0.92–1.72)	
Age ≥ 50 years	No. of cases	99	159	206	189	
	AOR (95% CI)	1.00 (ref.)	1.19 (0.90–1.57)	1.56 (1.19–2.05)	1.67 (1.26–2.22)	
Pre-HTN						< 0.001
Age < 50 years	No. of cases	363	444	575	751	
	AOR (95% CI)	1.00 (ref.)	1.30 (1.11–1.52)	1.84 (1.57–2.16)	2.59 (2.19–3.05)	
Age ≥ 50 years	No. of cases	222	335	525	545	
	AOR (95% CI)	1.00 (ref.)	1.07 (0.87–1.32)	1.56 (1.28–1.90)	1.73 (1.41–2.13)	
HTN						< 0.001
Age < 50 years	No. of cases	57	123	194	437	
	AOR (95% CI)	1.00 (ref.)	2.00 (1.44–2.78)	3.00 (2.19–4.12)	6.37 (4.68–8.69)	
Age ≥ 50 years	No. of cases	106	219	302	407	
	AOR (95% CI)	1.00 (ref.)	1.50 (1.16–1.96)	1.94 (1.50–2.51)	2.80 (2.16–3.62)	

Abbreviation: TyG, triglyceride and glucose; BP, blood pressure; HTN, hypertension; AOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index.

Adjusted for survey year, age, sex, BMI, marital status, education level, household income quartiles, smoking status, and frequency of binge drinking, except for the variable used in each stratified analysis.

Variables		Quartile of TyG index				p interaction
		Q1	Q2	Q3	Q4	
By sex						
Elevated BP						0.015
Male	No. of cases	86	115	125	168	
	AOR (95% CI)	1.00 (ref.)	1.00 (0.73–1.36)	0.98 (0.72–1.33)	1.32 (0.97–1.79)	
Female	No. of cases	124	134	182	127	
	AOR (95% CI)	1.00 (ref.)	1.02 (0.78–1.32)	1.53 (1.19–1.98)	1.55 (1.17–2.07)	
Pre-HTN						
Male	No. of cases	227	373	645	912	0.688
	AOR (95% CI)	1.00 (ref.)	1.13 (0.93–1.38)	1.61 (1.33–1.95)	2.06 (1.70–2.49)	
Female	No. of cases	358	406	455	384	
	AOR (95% CI)	1.00 (ref.)	1.24 (1.05–1.45)	1.71 (1.45–2.02)	2.19 (1.83–2.63)	
HTN						0.338
Male	No. of cases	64	143	268	576	
	AOR (95% CI)	1.00 (ref.)	1.43 (1.04–1.98)	2.09 (1.54–2.83)	3.85 (2.86–5.17)	
Female	No. of cases	99	199	228	268	
	AOR (95% CI)	1.00 (ref.)	1.89 (1.46–2.45)	2.33 (1.79–3.03)	3.83 (2.93–5.01)	
By BMI						
Elevated BP						0.527

Abbreviation: TyG, triglyceride and glucose; BP, blood pressure; HTN, hypertension; AOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index.

Adjusted for survey year, age, sex, BMI, marital status, education level, household income quartiles, smoking status, and frequency of binge drinking, except for the variable used in each stratified analysis.

Variables		Quartile of TyG index				*p* interaction
		Q1	Q2	Q3	Q4	
BMI < 25.0 kg/m^2	No. of cases	168	184	204	152	
	AOR (95% CI)	1.00 (ref.)	1.04 (0.83–1.30)	1.42 (1.13–1.78)	1.55 (1.21–1.99)	
BMI ≥ 25.0 kg/m^2	No. of cases	41	65	102	142	
	AOR (95% CI)	1.00 (ref.)	1.06 (0.69–1.63)	1.15 (0.77–1.71)	1.48 (1.00–2.18)	
Pre-HTN						0.635
BMI < 25.0 kg/m^2	No. of cases	469	556	676	571	
	AOR (95% CI)	1.00 (ref.)	1.21 (1.05–1.40)	1.83 (1.59–2.11)	2.17 (1.86–2.54)	
BMI ≥ 25.0 kg/m^2	No. of cases	115	220	423	723	
	AOR (95% CI)	1.00 (ref.)	1.28 (0.97–1.68)	1.68 (1.30–2.17)	2.40 (1.87–3.08)	
HTN						
BMI < 25.0 kg/m^2	No. of cases	132	213	271	348	
	AOR (95% CI)	1.00 (ref.)	1.47 (1.16–1.86)	2.20 (1.75–2.76)	3.85 (3.05–4.85)	0.730
BMI ≥ 25.0 kg/m^2	No. of cases	30	127	224	496	
	AOR (95% CI)	1.00 (ref.)	2.80 (1.82–4.31)	3.25 (2.15–4.91)	6.12 (4.10–9.15)	

Abbreviation: TyG, triglyceride and glucose; BP, blood pressure; HTN, hypertension; AOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index.

Adjusted for survey year, age, sex, BMI, marital status, education level, household income quartiles, smoking status, and frequency of binge drinking, except for the variable used in each stratified analysis.

Discussion

In this population-based cross-sectional study, the TyG index was positively associated with the increment in BP. Note that the study participants were apparently healthy individuals with no history of HTN or CVD and were not taking anti-diabetic or antihyperlipidemic medications. Even after adjusting for conventional risk factors, the significant association between the TyG index and BP was maintained. These findings suggest that the TyG index can predict HTN early.

IR has been implicated in the pathogenesis of diseases related to metabolic syndrome, including HTN, diabetes mellitus, obesity, and CVD[3,21,22]. The gold standard for assessing IR is hyperinsulinemic-euglycemic clamp analysis[23]. However, it is difficult to perform in real-world settings because it is time-consuming and labor-intensive. HOMA-IR has been suggested as a simpler method and its results correlated well with those assessed by the clamp analysis[24]. However, it also has limited value because serum insulin is not measured routinely in clinical settings. More recently, the TyG index has been proposed for evaluating IR[5]. In previous studies, the TyG index correlated well with HOMA-IR[5,7–9]. Because triglycerides and FPG can be assessed simply and easily, it is more suitable as a mass screening test to predict IR-related diseases, such as in our study.

Although the mechanisms underlying IR in the development of HTN have not been fully elucidated, several have been suggested. Hyperinsulinemia caused by IR may increase the activity of the renin-angiotensin-aldosterone system, which can induce renal sodium retention[25,26]. It can indirectly cause water-sodium retention and increase vascular activity via angiotensin II, resulting in HTN[27]. IR may also stimulate sympathetic nervous system activity, inducing the secretion of adrenaline and norepinephrine, leading to increased cardiac output and peripheral vascular resistance via vascular smooth muscle cell hypertrophy and endothelial dysfunction[28–30].

Several studies have evaluated the relationship between the TyG index and IR-related disease, especially in HTN. In a 9-year longitudinal study, a higher TyG index was associated with an increased risk of subsequent incident HTN[14]. A large epidemiological study of the temporal relationship between BMI and the TyG index and its impact on the incidence of HTN found that a higher BMI at baseline was significantly associated with a higher TyG index and an increased risk of HTN[31]. In addition, a higher TyG index was significantly associated with a higher BMI at the 2-year follow-up and an increased risk of HTN. These results provide direct evidence for a temporal relationship between BMI and IR. A more recent study demonstrated that an increased TyG index was significantly associated with a higher risk of pre-HTN and HTN.[15] Furthermore, obesity parameters such as the waist-to-hip ratio and percent body fat have additive effects on the HTN risk with the TyG index. Our results also showed a positive correlation between the TyG index and BP and prevalence of HTN in alignment with these previous studies.

This study examined subjects who had low risks for IR. Individuals who had previously been diagnosed with HTN, diabetes mellitus, dyslipidemia, or CVD were excluded. Nevertheless, a significant relationship was observed between the TyG index and BP; SBP in the lowest and highest quartiles was 109.1 ± 13.0 and 121.3 ± 15.3 mmHg, respectively (p for trend < 0.001) and DBP in the lowest and highest quartiles was 71.7 ± 8.5 and 80.0 ± 10.1 mmHg (*p* for trend < 0.001). In the subgroup analysis according to BMI, the TyG index was significantly associated with the prevalence of elevated BP, pre-HTN, and HTN, even in the non-obese subjects (BMI < 25 kg/m^2). Furthermore, the associations between the TyG index and the prevalence of pre-HTN and HTN were more prominent in younger subjects (*p* interaction < 0.001). Overall, these results suggest that the TyG index might be an early marker to identify patients with HTN.

This study has several advantages. It included relatively large number of subjects from a national health survey. We were able to analyze various confounding factors potentially influencing HTN (demographic, lifestyle, and laboratory parameters). In addition, the analysis examined categories of BP and subgroups by subject characteristics. However, our study also has some limitations that need to be considered. First, because of its cross-sectional design, it cannot show a causal relationship between the TyG index and HTN. Second, as KNHANES did not include fasting insulin, we could not compare the TyG index with the HOMA-IR as an independent risk factor. Third, although we tried to adjust for confounding risk factors, there might be some confounding factors that we did not include.

In conclusion, a higher TyG index significantly correlated with the risk of increased BP in healthy individuals after adjusting for conventional risk factors of HTN. Considering its simplicity of measurement and good functionality, the TyG index might be an early marker for identifying patients at risk of HTN.

Declarations

Data availability

Datasets related to this article can be found at https://knhanes.kdca.go.kr/knhanes/main.do. *The Korea National Health and Nutrition Examination Survey is public-use data provided by the Korea Disease Control and Prevention Agency.*

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Author contributions

DHL, JEP, SYK, HJJ, and JHP conceived and designed the study. JEP analyzed and summarized all the results. DHL and JEP wrote the manuscript. SYK, HJJ, and JHP reviewed the manuscript and contributed to the discussion. JHP supervised the project. All authors provided critical feedback and helped shape the research, analysis and manuscript.

Competing interests

The authors declare no competing interests.

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Figures

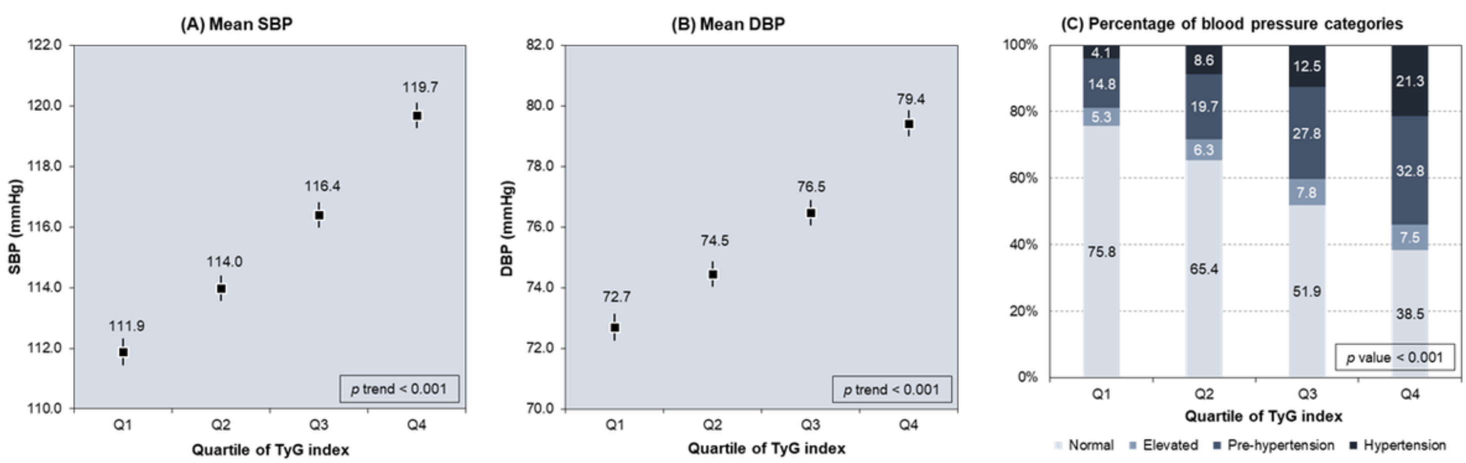

Figure 1

Distribution of blood pressure according to the quartile of the TyG index. Mean and 95% confidence interval (CI) of (A) systolic (SBP) and (B) diastolic (DBP) blood pressure adjusted for survey year, age, and sex. (C) Percentage distribution of blood pressure categories.