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The association of hypertriglyceridemic waist phenotype with hypertension: A cross-sectional study in a Chinese middle aged-old population

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Abstract

The present study aimed to evaluate the relationship between the hypertriglyceridemic waist (HTGW) phenotype and hypertension. We undertook a cross-sectional study with a sample of 9015 adults from China. The HTGW phenotype was defined as elevated waist circumference (WC) and elevated triglyceride (TG) concentration. Logistic regression analysis was used to evaluate the association between the HTGW phenotype and hypertension. The prevalence of hypertension was significantly higher in individuals with the HTGW phenotype, than in those with the normal waist normal triglyceride (NWNT) phenotype (89.9% vs 75.3%, respectively, $P < .001$). After adjusting for age, sex, BMI, current smoker, and current alcohol consumption, the HTGW phenotype was associated with hypertension (Odds Ratio (OR)1.53; 95% CI 1.25–1.87). After further adjustment for potential confounders, the HTGW phenotype was still significantly associated with hypertension (adjusted OR1.28; 95% CI 1.04-1.58) regardless of sex. The subgroup analyses generally revealed similar associations across all subgroups. This study indicated that the HTGW phenotype was strongly associated with hypertension, and blood pressure should be clinically monitored in individuals with the HTGW phenotype. We suggested a combined use of hypertriglyceridemia waist phenotype in identifying participants who are at high risk of hypertension.

KEYWORDS
central obesity, Chinese adults, hypertension, hypertriglyceridemia waist phenotype

1 | INTRODUCTION

With rapid lifestyle transitions such as westernization of diets and sedentary behavior, the prevalence of hypertension is increasing rapidly in China.[1] An epidemiologic study showed that the prevalence of hypertension was approximately 27.9% among Chinese adults and hypertension awareness, treatment, and control rates were 46.9%, 40.7%, and 15.3%, respectively.[2] In addition, hypertension was confirmed as an independent risk factor for cardiovascular disease (CVD), mortality[3] and disability.[4]

Previous studies demonstrated that lipid levels and obesity indices, especially visceral obesity, were associated with hypertension,[5–7]

cardiovascular diseases,[8] and chronic kidney disease (CKD),[9] In a follow-up study from Caucasian populations, triglyceride-related variables showed a stronger association with incident hypertension than other lipid parameters or lipid ratios.[10] On the other hand, as visceral obesity increases, blood pressure increases proportionately.[11] Waist circumference (WC),as a classical visceral obesity marker, has been widely used not only as a risk factor for hypertension[12,13] but also as a more effective parameter predicting risk factors for CVD.[14] The hypertriglyceridemic waist (HTGW) phenotype was first proposed in 2000, and defined as the presence of an elevated waist circumference, together with high levels of triglycerides (TGs).[15] Some previous studies showed the strong positive epidemiological associations of the HTGW phenotype with the risk of cardiovascular events,[16,17] prediabetes and diabetes,[18,19] chronic kidney disease,[20] and hyperuricemia.[21] However, to date, few studies have investigated the association of the HTGW phenotype and hypertension. Moreover, according to the Chinese Health and Retirement Longitudinal Study, the prevalence of hypertension was 44.7% among Chinese adults aged 40 years and older, but only 7.2% of them had achieved control.[22] It is necessary therefore to conduct a study on the incidence and risk factors for hypertension in middle-aged and elderly Chinese people.

Furthermore, previous studies on the HTGW phenotype rarely considered other simultaneous triglyceride waist phenotypes, which were always combined as a subgroup for analysis. Therefore, using the data collected in a community-dwelling Chinese population in this study, we aimed to explore the association of HTGW and three other triglyceride waist phenotypes with hypertension based on a middle-aged to elderly population in Shanghai, China.

2 | MATERIALS AND METHODS

2.1 | Study population

During March to August 2020, about 10 824 participates (aged ≥ 40 years) did health check in the health center of Luwan Branch of Ruijin Hospital, Huangpu district, Shanghai. First, from March to August 2020, individuals aged 40 years or older who were natives of Shanghai municipality or those who had lived in Shanghai for at least 5 years who underwent health checks in this health center were enrolled. Second, we invited participants to participate in the study by telephone. Participants were excluded if they met one of the following criterias: unable to consent; pregnancy; or critical illness such as cancer, organ transplant or dialysis treatments. At this stage, 10 826 participants were called. Third, 9214 participants provided informed consent and were recruited (response rate 85.1%). The exclusion criteria were as follows: missing blood pressure data (n = 2); missing triglyceride level (n = 122); and missing waist circumference (n = 75). Finally, 9015 patients were included in the analysis. (Figure 1)

The study protocol (No. LWEC2020024) was approved by the Ethics Committee of the Shanghai Ruijin Hospital, Luwan branch, Shanghai Jiao Tong University School of Medicine. Informed consent was obtained from all participants included in our study.

2.2 | Clinical, anthropometric, and laboratory measurements

A questionnaire covering sociodemographic characteristics, medical history, family history, and lifestyle factors was used during an interview by the same group of trained experienced personnel. Body mass index (BMI) was calculated as weight (in kilograms) divided by height (in meters squared). BMI < 24 kg/m² was defined as normal weight, while BMI ≥24 kg/m² was defined as overweight/obese, as determined by the Cooperative Meta-Analysis Group of the Working Group on Obesity in China criteria.[23] Blood pressure (BP) was measured by a trained physician with an electronic sphygmomanometer (Omron HEM-7200 Monitor, Batteries, and Stopwatch). The participants in this study were required to rest in a seated position for at least 5 minutes before the BP measurement, and BP was measured three times at 5-minute intervals. The mean of the three readings was calculated. A current smoker was defined as having smoked at least 100 cigarettes over a lifetime and still currently smoking.[24] A current drinker was defined as consuming alcohol regularly in the past 6 months.[25] Educational level was categorized as below high school or not. Physical activity included occupational and leisure-time physical activity, which were merged and regrouped into the self-reported high level of both occupational and leisure-time physical activity or below.[26]

Blood samples were obtained in the morning after fasting for at least 8 hours, and they were refrigerated immediately after phlebotomy and centrifuged within 2 hours of collection. Serum samples were aliquoted and frozen at a central laboratory. Glycated hemoglobin (HbA1c) was measured by a high-performance liquid chromatography (MQ-2000PT) (HPLC) automatic HbA1c analyzer (MEDCONN, Huizhong Medical Science and Technology Co., Ltd, Shanghai, China; Shanghai Huachen Biological Reagent Co., Ltd, Shanghai, China). Fasting plasma glucose (FPG), triglycerides (TG), total cholesterol, high-density lipoprotein (HDL-C) and low-density lipoprotein cholesterol (LDL-C), uric acid (UA) and serum creatinine were also measured (AU680 Chemistry Analyzer, Beckman Coulter, Brea, California, USA). TG was measured with assay kits from Beckman Coulter (catalog number: AUZ5612, assay sensitivity: 0.01 mmol/L, intra-assay variability: 6.25%), as was FPG (catalog number: AUZ4686, assay sensitivity: 0.04 mmol/L, intra-assay variability: 2.5%). Morning urine samples were collected in the refrigerator immediately to measure the levels of urine albumin and creatinine with a Beckman Coulter AU 680 (Brea, USA); then, the urine albumin to creatinine ratio (ACR) was calculated. The estimated glomerular filtration rate (eGFR) was calculated by the Chronic Kidney Disease Epidemiology Collaboration equation for Chinese individuals.[27]

2.3 | Definition of variables

Hypertension was defined as a systolic BP≥130 mmHg, diastolic BP≥80 mmHg, or self-reported use of antihypertensive medications in the past 2 weeks irrespective of BP according to the 2020 ACC/AHA guideline in this study.[28] Chronic kidney disease was defined as an
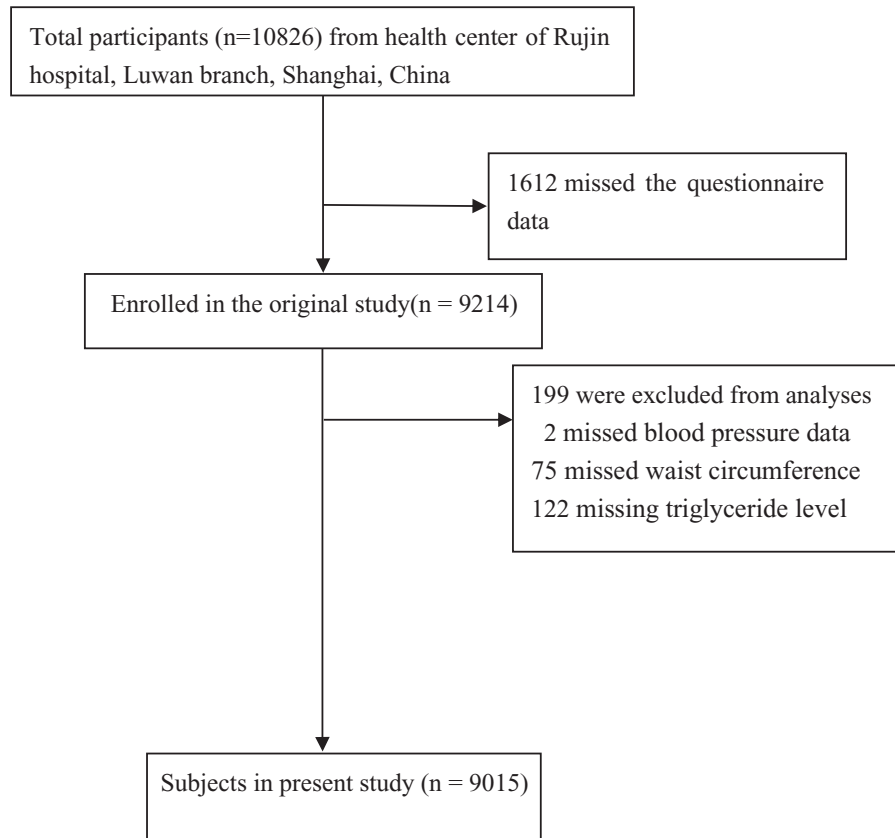
FIGURE 1 Flow chart describing the enrollment of the subjects in this study

estimated glomerular filtration rate less than 60 mL/min/1.73 m^2 and urinary albumin creatinine ratio $\geq$ 30 mg/g, and it was defined as CKD.[29]

2.4 | Definitions of HTGW and the rest of the phenotypes

Participants were grouped into four phenotype groups according the measurements of TG and WC: (1) NWNT: normal waist circumference and normal triglycerides (TG $\leq$ 1.7 mmol/L, WC < 90 cm for men and WC < 80 cm for women); (2) NWET: normal waist circumference and elevated triglycerides (TG > 1.7 mmol/L, WC < 90 cm for men and WC < 80 cm for women); (3) EWNT: elevated waist circumference and normal triglycerides (TG $\leq$ 1.7 mmol/L, WC $\geq$ 90 cm for men and $\geq$80 cm for women); and (4) HTGW: hypertriglyceridemic waist (TG > 1.7 mmol/L, WC $\geq$ 90 cm for men and $\geq$80 cm for women).[30]

2.5 | Statistical analyses

Data analyses were performed using IBM SPSS version 25 statistical software (IBM Corp., Armonk, New York, USA). P < .05 indicated significance (two-sided). Continuous variables were presented as the mean $\pm$ standard deviation (SD), and categorical variables were presented as percentages (%) when appropriate.

Logistic regression was performed to evaluate the association between the four phenotype groups and hypertension. Model 1 was adjusted for age, sex, BMI, current smoker, and current drinker. Model 2 was adjusted for Model 1 plus TC, LDL, HbA1c, UA, eGFR, physical activity, education status, systolic blood pressure (SBP), diastolic blood pressure (DBP), diabetes, anti-diabetic agents, anti-hypertensive drugs. In addition, stratified analyses by sex, BMI and presence of diabetes, current smoker, and current drinker were performed.

A receiver operating characteristic (ROC) curve analysis which was quantified by the area under the ROC curve (AUC) was used to evaluate the value of TG, WC, and combined TG and WC for predicting hypertension by comparing the area under the ROC curve.

3 | RESULTS

3.1 | Baseline clinical characteristics

The baseline anthropometric parameters and biochemical indices according to four triglyceride waist phenotypes are shown in Table 1. Participants with the HTGW phenotype were older and had a significantly higher BMI, WC, SBP, and DBP than the NTNW group; Higher

TABLE 1 Characteristics of the participants in each phenotype group (No. = 9015)

	NWNT	NWET	EWNT	HTGW	P for trend
No. of participants (%)	3410(37.8)	2375(14.7)	1321(26.3)	1909(21.2)	
Age at baseline (year)	60.25±10.91	63.13±9.56	63.63±9.0	64.08±9.68	.077
Male (%)	1716(50.3)	733(55.4)	712(29.9)	772(33.6)	.192
BMI (kg/m²)	23.21±2.98	24.37±3.21	25.19±3.21	25.85±3.10	<.001
WC(cm)	81.54±8.49	83.95±8.45	86.15±8.34	87.72±8.23	<.001
SBP (mmHg)	126.59±16.58	129.17±17.45	137.30±18.31	140.25±18.71	.013
DBP (mmHg)	85.90±10.78	84.50±10.53	86.53±9.92	85.79±10.07	<.001
FBG (mmol/L)	4.75±1.19	5.03±1.70	5.39±1.63	6.70±1.71	<.001
HbA1C (%)	5.49±0.68	5.62±1.03	5.81±0.97	6.50±0.97	<.001
TG (mmol/L)	1.54±1.42	1.68±0.94	1.70±1.15	1.68±1.19	<.001
TC (mmol/L)	4.78±0.75	5.02±0.85	5.39±0.81	6.70±0.93	<.001
HDL-C (mmol/L)	1.62±0.33	1.45±0.33	1.33±0.29	1.17±0.27	<.001
LDL-C (mmol/L)	2.97±0.71	3.28±0.74	3.45±0.79	3.33±0.80	<.001
eGFR (mL/m/1.73 m2)	101.89±11.13	92.87±12.01	87.89±11.25	82.53±12.09	<.001
uACR (mg/g)	45.30±177.07	48.57±242.90	54.95±164.43	95.34±324.57	<.001
UA (mmol/l)	300.98±78.12	319.38±79.10	331.38±82.41	348.28±87.51	<.001
CKD, (%)	106(3.2)	88(6.6)	207(8.8)	168(8.8)	<.001
Hypertension, (%)	2570(75.3)	2001(84.2)	1138(86.1)	1717(89.9)	<.001
Male, (%)	1384(53.8)	639(31.9)	647(56.8)	593(34.5)	<.001
Diabetes (%)	286(8.4)	153(11.6)	370(15.6)	594(19.6)	<.001
Overweight/obesity, (%)	1046(30.7)	635(48.1)	1669(70.3)	1777(93.1)	<.001
Current smoker (%)	504(14.8)	204(15.5)	477(20.1)	488(25.6)	<.001
Current drinker (%)	79(2.34)	28(2.12)	61(2.56)	53(2.78)	<.001
Education (≥high school), %	180(5.3)	61(4.6)	171(7.2)	120(6.3)	<.001
High physical activity, %	286(8.4)	95(7.2)	114(4.8)	61(3.2)	<.001

Data are expressed as the mean SD, median value [interquartile range] or as n (%), as appropriate.

Abbreviations: BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting blood glucose; TC, total cholesterol; TG, triglycerides; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; eGFR, estimated glomerular filtration rate; uACR, urinary albumin creatinine ratio; UA, uric acid

levels of TC, TG, LDL-C, FPG, HbA1c, UA, and uACR; and lower levels of HDL-C and eGFR was found in the HTGW phenotype group (P < .001, Table 1). Patients with the HTGW phenotype were more likely to be current smokers and current drinkers and less likely to engage in physical activity (P < .001). Patients with the HTGW phenotype also had a higher prevalence of a history of diabetes, cardiovascular diseases, and CKD than those in the other three groups (P < .001). In Table 1, the prevalence of hypertension was 82.3% (7426/9015). Participants in the HTGW group had the highest prevalence of hypertension (1717/1909 (89.9%)) among the four subgroups (P < .001). Participants in the NWET and EWNT groups had a higher prevalence of hypertension (2001/2375 (84.2%) and 1138/1321 (86.1%), respectively) than those in the NWNT Group (2570/3410 (75.3%)) (P < .001). Data from our study showed that women had a higher prevalence of hypertension than men in the NWET and HTGW groups.

3.2 | Association of the different triglyceride waist phenotypes with hypertension

In logistic regression models, the HTGW phenotype was positively associated with the risk of hypertension in patients (Table 2). After adjusting for age, sex, BMI, smoking status, and drinking status, patients with the HTGW phenotype had 1.53 times (95% confidence interval (CI)1.25–1.87) more likely to have hypertension than those with the NWNT phenotype. After full adjustments, the OR (95% CI) of hypertension was 1.28 (1.04, 1.58) for participants with the HTGW phenotype than those with the NWNT phenotype. After stratification by sex (P < .0001 for interaction with sex), the HTGW phenotype was associated with hypertension after full adjustments in men (1.03, 95% CI: 1.01-1.04, P < .001) and women (1.37, 95% CI: 1.07-1.77, P < .05).

TABLE 2 Odds ratios for hypertension at different levels of triglyceride waist phenotypes

	Hypertension			
	Model 1	P value	Model 2	P value
Total				
NWNT	ref	ref	ref	ref
NWET	1.03(1.02,1.04)	<.001	1.01(0.85,1.19)	.960
EWNT	1.69(1.42,2.02)	<.001	1.48(1.23,1.78)	<.001
HTGW	1.53(1.25,1.87)	<.001	1.28(1.04,1.58)	.019
Men				
NWNT	ref	ref	ref	ref
NWET	1.06(0.78,1.45)	.715	1.05 (0.76,1.43)	.786
EWNT	1.57(1.21,2.04)	<.001	1.37(1.04,1.79)	.025
HTGW	1.33(0.92,1.91)	.126	1.03(1.01,1.04)	<.001
Women				
NWNT	ref	ref	ref	ref
NWET	1.01(0.82,1.23)	.101	1.01 (0.82,1.23)	.979
EWNT	1.76(1.37,2,25)	<.001	1.56 (1.21,2.01)	.001
HTGW	1.59(1.25,2.04)	<.001	1.37 (1.07,1.77)	.014

Model 1 was adjusted for age, sex, BMI, current smoker, and current drinker. Model 2 was adjusted for model 1 plus TC, LDL, HbA1c, UA, eGFR, physical activity, education status, systolic blood pressure, diastolic blood pressure, diabetes, anti-diabetes agents, anti-hypertension drug.

Furthermore, we used logistic regression to examine the association of triglyceride waist phenotypes with hypertension in different subgroups of age, BMI, diabetes, current smoker, and current drinker in Table 3. The associations between different triglyceride waist phenotypes and the risk of hypertension remained consistent across almost all subgroups. A stronger positive association of the HTGW phenotype with hypertension was found in the subgroup of current smoker (OR 2.97, 95% CI 1.58–5.56) and the presence of diabetes (OR 2.89, 95% CI 1.42–5.85). No significant interaction effect was observed between the triglyceride waist phenotypes and all subgroup variables in hypertension risk.

3.3 | The AUCs (and 95% CIs) of variables in the HTGW measurement for hypertension

In addition, we drew the ROC curve according to the two continuous variables and combined the two variables in the HTGW measurement and prevalence of hypertension (Table 4). The discriminatory power of TG and WC in the prediction of hypertension was detected (AUC 0.609, 95% CI 0.594–0.624 for TG; AUC 0.643, 95% CI 0.628–0.658 for WC). The sensitivity and specificity in hypertension identification for TG were 73.7% and 60.5% and the cutoff was 1.05 mmol/L, while the sensitivity and specificity for WC were 76.9% and 58.5% and the cutoff was 77 cm. The discriminatory power of combined TG and TC

TABLE 3 Odds ratios for hypertension according to triglyceride waist phenotypes by various subgroups

Subpopulation	Cases/Participants	NWNT	NWET	EWNT	HTGW	P-trend	P-interaction
Age, years[b]							
<60	2316/9015	1.00(ref)	1.18(0.86,1.63)	1.71(1.23,2.36)	1.99(1.26,3.13)	<.001	.542
≥60	6699/9015	1.00(ref)	0.91(0.75,1.12)	1.59(1.28,1.99)	1.28(1.01,1.62)	<.001	
BMI, kg/m[2c]							
< 24	4978/9015	1.00(ref)	1.06(0.82,1.37)	1.72(1.38,2.14)	2.21(1.46,3.33)	<.001	.678
≥ 24	4037/9015	1.00(ref)	1.04(0.81,1.33)	1.27(0.91,1.78)	1.44(1.11,1.88)	.008	
Presence of T2DM[d]							
No	7612/9015	1.00(ref)	1.57(1.35,1.82)	1.73 (1.44,2.08)	2.36 (1.95,2.86)	<.001	.784
yes	1403/9015	1.00(ref)	1.45(0.86,2.45)	1.95(1.12,3.38)	2.89(1.42,5.85)	<.001	
Current smoker[e]							
No	7342/9015	1.00(ref)	1.62(1.39,1.88)	1.79(1.48,2,17)	2.31(1.92,2.79)	<.001	.458
Yes	1673/9015	1.00(ref)	1.19(0.73,1.96)	2.21(1.31,3.76)	2.97(1.58,5.56)	.001	
Current drinker[f]							
No	8794/9015	1.00(ref)	1.64 (1.41,1.89)	1.94 (1.61,2.33)	2.49(2.08,2.98)	<.001	.262
Yes	221/9015	1.00(ref)	1.28 (0.60,2.72)	0.72 (0.31,1.66)	1.66 (0.68,4.03)	.389	

[b]for age subgroup: adjusted for sex, BMI, LDL-C, HDL-C, TC, FBG, HbA1c, eGFR, UA, physical activity, education status, current smoker and current drinker, systolic blood pressure, diastolic blood pressure, diabetes, anti-diabetes agents, anti-hypertension drug; [c] for BMI subgroup: adjusted for age, sex, LDL-C, HDL-C, TC, FBG, HbA1c, eGFR, UA, physical activity, education status, current smoker and current drinker, systolic blood pressure, diastolic blood pressure, diabetes, anti-diabetes agents, anti-hypertension drug; [d] for T2DM subgroup: adjusted for age, sex, BMI, LDL-C, HDL-C, TC, FBG, HbA1c, eGFR, UA, physical activity, education status, current smoker, and current drinker, systolic blood pressure, diastolic blood pressure, anti-diabetes agents(only for diabetes group), anti-hypertension drug; [e] for smoke status subgroup: adjusted for age, sex, BMI, LDL-C, HDL-C, TC, FBG, HbA1c, eGFR, UA, physical activity, education status, current drinker, systolic blood pressure, diastolic blood pressure, anti-diabetes agents, anti-hypertension drug; [f] for drink status subgroup: adjusted for age, sex, BMI, LDL-C, HDL-C, TC, FBG, HbA1c, eGFR, UA, physical activity, education status, current smoker; systolic blood pressure, diastolic blood pressure, anti-diabetes agents, anti-hypertension drug;.

TABLE 4 Area under the receiver operating characteristic curve (AUC) of variables in the HTGW measurement for the presence of hypertension in both genders

Variables	AUC	95% CI	Cut-off point	Sensitivity	Specificity	Youden index
Total						
TG, mmol/L[*]	0.609	0.594-0.624	1.05	0.74	0.61	0.35
WC, cm[*]	0.643	0.628-0.658	77	0.77	0.59	0.36
TG*WC[*]	0.658	0.643-0.673	0.78	0.79	0.64	0.43
Men						
TG, mmol/L[*]	0.585	0.560-0.610	1.05	0.73	0.63	0.36
WC, cm[*]	0.641	0.615-0.666	80	0.78	0.59	0.37
TG*WC[*]	0.650	0.625-0.676	0.78	0.77	0.65	0.42
Women						
TG, mmol/L[*]	0.624	0.605-0.642	1.05	0.75	0.59	0.34
WC, cm[*]	0.628	0.609-0.647	75	0.77	0.60	0.37
TG*WC[*]	0.649	0.630-0.667	0.78	0.79	0.62	0.41

[*]$P < .001$.

in the prediction of hypertension was detected (AUC 0.658, 95% CI 0.643–0.673), the cutoff point is 0.78. The sensitivity and specificity in hypertension identification were 79% and 64% for combined TG and WC, respectively. The results were consistency in men and women.

4 | DISCUSSION

In this large population-based, cross-sectional study, we explored the association of triglyceride waist phenotypes with hypertension in the overall population and across a variety of subgroups. We found that the HTGW phenotype was associated with an increased risk of hypertension compared with the other three phenotype groups. Patients with the HTGW phenotype were 1.53-fold more likely to have hypertension than those with the NWNT phenotype. The major finding of this current study was that the HTGW phenotype was indicated as a strong risk factor for hypertension for both sexes in this middle-aged to elderly Chinese population. This is the first study assessing the association of the HTGW phenotype with hypertension in China. In addition, this positive relationship was independent of age, sex, BMI, history of diabetes, CKD, smoking, drinking, physical activity, and education status.

Hypertension is responsible for enormous health care burdens worldwide. This is especially true in China due to rapid changes in lifestyle and the aging population. Our study shows that the prevalence of hypertension in a middle-aged and older population was 82.3%,51.2% in men, and 48.8% in women, respectively. The hypertension prevalence of the NWNT, NWET, EWNT, and HTGW phenotype groups was 75.3%, 84.2%, 86.1%, and 89.9%, respectively. In view of the newly selected hypertension BP threshold definition (systolic or diastolic BP values of ≥130 mmHg or ≥80 mmHg) and the bias for participant choice, hypertension was much higher than that in previous studies.[2] Assuming that new hypertension guidelines are adopted in China, the high prevalence of hypertension will arouse more urgent

attention. In addition, hypertension is the top risk factor for both number of deaths and percentage of disability-adjusted life-years (DALYs), of which 95.7% were due to CVD.[31] Given the huge social burden and strong association of hypertension with cardiovascular events, identifying high-risk asymptomatic individuals for hypertension is of critical importance. In addition, our study observed that the distribution of phenotype groups varied by sex. Women had a higher proportion of HTGW and EWNT phenotypes than men, probably as a result of the higher prevalence of central obesity and dyslipidemia in elderly women in China.[32]

The present study provides evidence that systolic blood pressure in the HTGW group was 14 mmHg higher than that in the NTNW group. The participants with HTGW were 1.28-fold as likely to have hypertension as those with normal waist circumference and TG concentration (NWNT), independent of age, sex, diabetes, and other potentially confounding factors. We found that only a longitudinal study, including 10 312 non-hypertensive participants aged at least 18 showed that hypertriglyceridemic waist-to-height ratio (HWHtR) phenotype and its dynamic status were associated with incident hypertension in rural Chinese men, and HWHtR may be an indicator for interventions aiming to reduce hypertension among these men.[33] The biological mechanisms linking HTGW and hypertension are still unclear, but the critical role of current acknowledged hypotheses is visceral obesity[34] which can induce a state of insulin resistance. In the present study, we found that the prevalence of type 2 diabetes was higher in the HTGW phenotype group than in the NTNW group (19.6% vs 8.4%). The participants with the HTGW phenotype simultaneously had elevated glucose (FBG, 6.70 vs 4.75 mmol/L) and poor glucose control (HbA1c, 6.50% vs 5.49%) compared with those in the NTNW group. This situation leads to increasing insulin. Then, insulin enhances the adrenergic system, increasing the activity of the sympathetic nervous system, thus elevating blood pressure. It also inhibits the stimulating effect of adrenergic agonists producing prostacyclin in adipose tissue, which can in turn increase peripheral vascular resistance and hypertension. Insulin

modulates intracellular cation regulation by reducing the activity of sodium/potassium ATPase (Na+/K+ ATPase) enzymes and increasing the Na+/K+ pump of vascular smooth muscle cells, increasing their sensitivity to catecholamines and angiotensin II, and finally increasing peripheral resistance, thus causing hypertension.[35] In addition, IR factors, including nonesterified fatty acids, cytokines, and adiponectin, are released from excess adipose tissue. These factors increase the ability of the vascular endothelium to affect the elasticity of blood vessels, causing hypertension.[35] Moreover, activation of the Renin-angiotensin-aldosterone System (RAAS) is another important mediator of elevated blood pressure under circumstances of obesity. Significant angiotensin II (AngII) and angiotensinogen (AGT) secretion from abdominal subcutaneous adipose tissue has clearly been demonstrated in both animal and human adipose tissue.[36,37] Thus, it is likely that adipose tissue-derived RAAS components are involved in the regulation of blood pressure. This is attributable not only to sympathetic nervous system overactivity and renal compression but also to dysfunctional adipose tissue.[37]

It is interesting to note that the uACR level was nearly double as high in the HTGW group compared to the NTNW group (105 vs 78 mg/g). eGFR was significantly decreased (82.53 vs 101.89 mL/m/1.73 m^2) in HTGW compared with NTNW and there was a high prevalence of CKD (8.8% vs 3.2%). A previous study showed that increased vulnerability of the glomerular microcirculation to elevated systemic blood pressure is postulated to contribute to adverse effects of obesity on the kidney.[38] Consistent with our findings, there was a strong association between the HTGW phenotype and decreased eGFR risk found in participants with hypertension in a cross-sectional study among Chinese participants.[20] In another human study, increased systolic blood pressure was associated with a greater increase in albuminuria in obese people.[39] The probable mechanism of this phenomenon was the association between obesity and fatty kidney disease.[40] The term "fatty kidney," first appearing in the literature in 1883,[41] suggests that hyperlipidemia is the cause of the characteristic renal lipid accumulation and nephrotoxicity.[40] Obesity itself is associated with increased renal tubular sodium reabsorption followed by initial hyperfiltration and a subsequent gradual decline in the estimated glomerular filtration rate.[7] Adipocytes are able to secrete all components of the RAAS and are upregulated in obesity.[42] Therefore, the kidney is not just a victim but rather an active coconspirator in metabolic syndrome.

In subgroup analyses, the association between the HTGW and hypertension remained significant for all subgroups. The strongest association were found in the current smoker and patients with type 2 diabetes. Previous evidence has shown that smoke status and diabetes were strong risk factors for hypertension in Chinese obesity population.[43] The similar results were found in Korea study as well.[44] Consistence with other studies, diabetes, and current smoker were the obvious risk factors of hypertension.[45]

Previous studies on HTGW phenotypes have always combined EWNT and NWET phenotypes into one group for analysis which may miss their effect on the disease outcome. Our study observed that patients with the EWNT phenotype had an increased risk of hypertension in both sexes, while the adjusted OR for hypertension with the NWET phenotype was always less than 1, but without significance. Hence, this divergence raised a further question of whether the contributions of waist circumference and TGs to hypertension were actually different. A previous mechanistic study has reported that TG was proposed to be a marker of visceral obesity in a given waist circumference, but it was unable to distinguish between visceral and subcutaneous abdominal obesity.[46] Another considerable factor was race difference according to the Chinese predisposition to visceral fat accumulation, even with generally low BMI.[47]

Several limitations in this study need to be considered. First, the temporal and causal relationship could not be assessed with a cross-sectional design. Further prospective studies are needed to test these results and potential mechanisms. Second, the definition of HTGW is currently diverse, and there is no specialized cutoff set for Chinese populations. Third, although multiple variables were adjusted, other confounding factors, such as diet, and recent usage of medicines, may exist. Fourth, given the non-nationally representative of this study, caution is required to generalize the obtained results. Future investigations covering more elderly patients (≥80 years) or those younger than 40 years and the rural population are warranted.

5 | CONCLUSION

In summary, a strong association was observed between HTGW and hypertension in a middle-aged to elderly population of Shanghai, China. Both genders with HTGW were more likely to have hypertension than those with NWNT, which also applies in relation to the risk of hypertension and the EWNT phenotype. Hence, more attention should be given to TG concentration and waist circumference in clinical screening and intervention. Furthermore, future large-scale prospective studies for uncertain sex-specific associations and other potential mechanisms are still essential.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

In this study, X. Y., S. Y., and W.S. J. were mainly responsible for the writing of the article, C. L. and L. L. Q. were mainly responsible for research, G. X. was mainly responsible for data entry, G.P. and T. D. were mainly responsible for data calculation and correction, and W. X and

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