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RESEARCH

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Comparison of the predictive value of 17 anthropometric in-dices for the prevalence of metabolic syndrome among Chinese residents: a cross-sectional study

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Abstract

Background Metabolic syndrome (MetS) is increasingly viewed as a pressing concern for public health globally. The objective of this study was to compare the predictive ability of 17 anthropometric indices for the risk of MetS in Chinese residents, to explore the differences in the predictive effect of the indices between different sexes, and to identify the optimal predictive indices of MetS for men and women.

Methods This research utilized a cross-sectional study involving 5479 residents in Shandong Province, China. According to the subjects' working curve (ROC), TyG-WHtR, TyG-WC, METS-VF, CVAI, and LAP with the area under the curve (AUC) greater than 0.850 were included in the follow-up. To explore the associations between indices and the prevalence of MetS, three logistic regression models were employed. The dose–response relationship between the indices and the risk of MetS was performed by the Restricted cubic spline (RCS) curves.

Results The prevalence of MetS in this study is approximately 45.56%. The multivariate logistic regression showed the predictive capacity of the TyG-WC and METS-VF for MetS was superior in males, while only METS-VF in females. Furthermore, there is a non-linear relationship between MTES-VF and MetS risk both in men and women (non-linearity $p < 0.001$). The potential for the risk of MetS increased when the METS-VF exceeded 6.67 in males or 6.30 in females. In addition, in the male population, TyG-WC is non-linearly related to MetS risk (non-linear $p < 0.001$), and the risk of MetS may increase when TyG-WC is higher than 750.40.

Conclusions TyG-WC and METS-VF have a good predictive value for the risk of MetS in the Chinese male population, with TyG-WC being better than METS-VF. For females, METS-VF could be regarded as the most reliable indicator.

Keywords Metabolic syndrome, Anthropometric indices, TyG-WC, METS-VF

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Background

Metabolic syndrome (MetS) represents an intricate condition characterized by central obesity, dyslipidemia, hypertension, and hyperglycemia [1]. As a complex state of pathophysiology, MetS has been extensively acknowledged as a pivotal risk factor for a multitude of clinical conditions, including type 2 diabetes, diverse forms of cancer, chronic kidney disease, liver disease, and cardiovascular disease [2, 3]. Extensive data indicates that approximately 25% to 30% of adults globally are affected by this syndrome, with projections suggesting a persistent upward trend [4, 5]. Most recently, there is a trend towards a lower-age prevalence of MetS. It was estimated that around 2.8% of children and 4.8% of adolescents worldwide had MetS [6]. A study based on the China population revealed that the prevalence of MetS among 7–17-year-old students in 2016–2017 was 5.45% [7]. This study also shows that high levels of sedentary time and screen time were associated with an increased likelihood of MetS. In China, the current prevalence of MetS exhibits distinct characteristics, including a high incidence rate and substantial gender disparities. According to the latest data presented in the 2023 'Guidelines for the Diagnosis and Treatment of Metabolic Syndrome,' the prevalence of MetS among individuals aged 20 and older in China has reached a notably high level of 31.1% [8], further underscoring the significant incidence of this condition within the Chinese population. In light of the high prevalence of MetS and the considerable health risks it presents to patients [9], the early identification of individuals at risk for MetS and the implementation of intervention measures are paramount in alleviating the burden on public health and enhancing the quality of life for patients.

Multiple diagnostic strategies are available for the identification of MetS. Among these, the assessment of insulin sensitivity, a pivotal element of its fundamental pathophysiological mechanism, is paramount for attaining a comprehensive understanding of a patient's metabolic status and forecasting the risk of long-term complications, such as cardiovascular disease [10]. However, the process of testing insulin sensitivity is complex, dependent on sophisticated equipment and professional expertise, and time-consuming, thereby limiting its widespread clinical application. In addition, imaging techniques such as ultrasound and CT can provide a visual representation of the distribution of visceral fat and vascular lesions [11]. However, the high costs associated with these techniques often impose a financial burden on patients, limiting their feasibility as routine tools for early metabolic syndrome screening.

In recent years, anthropometric indices, including the Chinese visceral fat index (CVAI) [12], lipid accumulation index (LAP) [13], visceral fat metabolic score (METS-VF) [14], and triglyceride-glucose index (TyG) [15], have exhibited both accuracy and feasibility in the early diagnosis of MetS. These indices have undergone validation in diverse populations and have proven effective in assessing the distribution of visceral adipose tissue, as well as predicting the risk of MetS [16–18]. It is particularly crucial that anthropometric indices are suitable for application at both primary medical care and community levels, due to their user-friendliness and cost-effectiveness [19]. Although current research has extensively examined the relationship between various anthropometric indices and MetS, the majority of studies have centered on evaluating the predictive efficacy of individual or a limited number of indices [20–22], it is not clear which indices can be more reliable indices for predicting MetS. It's worthy that the optimal indicator for identifying MetS in adolescents also remains controversial [23].

The risk of MetS exhibits a significant difference in gender dimension. These differences are primarily attributed to physiological variations in hormone levels, which impact the physical characteristics of men and women. Specifically, disparities in hormonal regulation mechanisms give rise to fundamental differences between the sexes in fat distribution, metabolic efficiency, and energy balance. Notably, following menopause, women frequently become more susceptible to visceral fat accumulation due to a reduction in estrogen levels [24]. Therefore, it is necessary to explore and optimize more accurate anthropometric indicators for different gender groups to ensure the accuracy of the assessment results.

This study selected 17 anthropometric indices, including indices linked to MetS in traditional studies, along with the latest indices derived from recent research, such as CVAI, TyG index, and TyG-WC. The study was stratified by gender to comprehensively consider the impact of gender differences on MetS risk. The objective was to ascertain the predictive ability of each index for MetS risk in different gender groups and then identify the optimal index. This endeavor aims to enrich the theoretical framework of MetS risk assessment and provide a foundation for developing more precise and personalized MetS prevention strategies.

Methods

Study design and participants

This is a cross-sectional study. A total of 6027 permanent adult residents of Shandong Province who participated in a chronic disease risk factor survey between July and September 2022 were selected as study participants. The process of choosing study subjects is shown in Fig. 1. Invalid questionnaires were excluded. All participants provided informed consent.

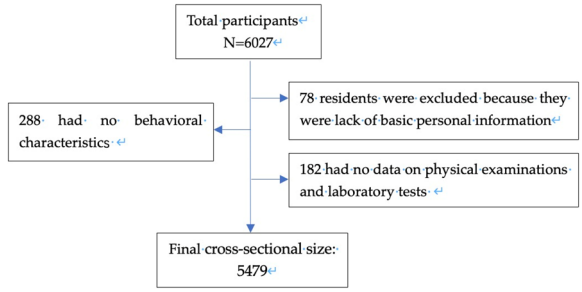


Fig. 1 The process of study participants' selection

Data collection

Basic characteristics about general demographics (sex, age, current residence, occupation, marital status, income status, and education), family history of chronic diseases (hypertension, diabetes, hyperlipidemia, cancer, and coronary heart disease), and behavioral lifestyles (smoking, drinking, and low-risk sleep duration) were obtained from the questionnaire using one-on-one interviews. Standard testing procedures were conducted by licensed professional examiners to perform physical assessments on all residents. Fasting blood samples were taken to measure blood biochemical indicators such as triglycerides.

Definition of metabolic syndrome

The diagnosis proposed by the Diabetes Section of the Chinese Medical Association in 2020 [25] will be used to determine MetS. The criteria specify that three or more of the following should be met: (1) Waist circumference ≥ 85 cm in females and ≥ 90 cm in males, (2) Blood pressure ≥ 130/85 mmHg or had been diagnosed with hypertension, (3) Elevated triglycerides (TG) ≥ 150 mg/dL or drug treatment for raised TG, (4) High-density lipoprotein cholesterol (HDL-C) for males < 40 mg/dL, and < 50 mg/dL in females or drug treatment for reduced HDL-C, (5) Fasting blood glucose ≥ 100 mg/dL or had been diagnosed with diabetes mellitus.

Anthropometric indices

17 anthropometric indices were involved, including the body mass index (BMI), waist-to-height ratio (WHtR), visceral adiposity index (VAI), body shape index (ABSI), body roundness index (BRI), lipid accumulation product (LAP), conicity index (CI), Chinese visceral fat index (CVAI), triglyceride-glucose (TyG) index and its related indices (TyG-WC, TyG-WHtR, TyG-BMI), waist triglyceride index (WTI), plasma atherogenic index (AIP), insulin resistance metabolic score (METS-IR), visceral fat metabolic score (METS-VF), and cardiometabolic index (CMI). The respective formulas for calculating these indices are outlined below [26–39]:

$$\mathrm{BMI} = \frac{\mathrm{weight}}{\mathrm{height}^2} \tag{1}$$

$$\mathrm{WHtR} = \frac{\mathrm{waist}}{\mathrm{height}} \tag{2}$$

$$\text{Males: } \mathrm{VAI} = \frac{\mathrm{waist}}{39.68 + 1.88 \times \mathrm{BMI}} \times \frac{\mathrm{TG}}{1.03} \times \frac{1.31}{\mathrm{HDL}} \tag{3}$$

$$\text{Females: } \mathrm{VAI} = \frac{\mathrm{waist}}{36.58 + 1.89 \times \mathrm{BMI}} \times \frac{\mathrm{TG}}{0.81} \times \frac{1.52}{\mathrm{HDL}} \tag{4}$$

$$\mathrm{ABSI} = \frac{\mathrm{waist}}{\mathrm{height}^{\frac{1}{2}} \times \mathrm{BMI}^{\frac{2}{3}}} \tag{5}$$

$$\mathrm{BRI} = 364.2 - 365.5\sqrt{1 - \frac{\mathrm{waist} \div 2\pi^2}{\mathrm{height}}} \tag{6}$$

$$\text{Males}: \ \mathrm{LAP} = [\mathrm{waist} - 65] \times \mathrm{TG} \tag{7}$$

$$\text{Females}: \ \mathrm{LAP} = [\mathrm{waist} - 58] \times \mathrm{TG} \tag{8}$$

$$\mathrm{CI} = \frac{\mathrm{waist}}{0.019\sqrt{\frac{\mathrm{weight}}{\mathrm{height}}}} \tag{9}$$

$$\begin{aligned}\text{Males: } \mathrm{CVAI} = &-267.93 + 0.68 \times \mathrm{age} + 0.03 \\ &\times \mathrm{BMI} + 4 \times \mathrm{waist} + 22 \times \mathrm{Log}_{10}\mathrm{TG} \\ &- 16.32 \times \mathrm{HDL} - \mathrm{C}\end{aligned} \tag{10}$$

$$\begin{aligned}\text{Females: } \mathrm{CVAI} = &-187.32 + 1.71 \times \mathrm{age} + 4.32 \\ &\times \mathrm{BMI} + 1.12 \times \mathrm{waist} + 39.76 \\ &\times \mathrm{Log}_{10}\mathrm{TG} - 11.66 \times \mathrm{HDL} - \mathrm{C}\end{aligned} \tag{11}$$

$$\mathrm{TyG\ index} = \mathrm{Ln}[\mathrm{TG} \times \mathrm{FPG}/2] \tag{12}$$

$$\mathrm{TyG} - \mathrm{BMI} = \mathrm{TyG} \times \mathrm{BMI} \tag{13}$$

$$\mathrm{TyG} - \mathrm{WHtR} = \mathrm{TyG} \times \mathrm{WHtR} \tag{14}$$

$$\mathrm{TyG} - \mathrm{WC} = \mathrm{TyG} \times \mathrm{WC} \tag{15}$$

$$\mathrm{WTI} = \mathrm{waist} \times \mathrm{TG} \tag{16}$$

$$\mathrm{AIP} = \lg(\mathrm{TG}/\mathrm{HDL} - \mathrm{C}) \tag{17}$$

$$\mathrm{MET} - \mathrm{IR} = \mathrm{Ln}\left[(2 \times \mathrm{FPG}] + \mathrm{TG} \times \frac{\mathrm{BMI}}{\mathrm{Ln}[\mathrm{HDL} - \mathrm{C}]}\right) \tag{18}$$

$$\begin{aligned}\text{Males: } \mathrm{METS} - \mathrm{VF} = {} & 4.466 + 0.011 \times (\mathrm{Ln}(\mathrm{METS} - \mathrm{IR}))^3 \\ & + 3.239 \times (\mathrm{Ln}(\mathrm{WHtR}))^3 + 0.319 \times 1 \\ & + 0.594 \times \mathrm{Ln}(\mathrm{age})\end{aligned} \tag{19}$$

$$\begin{aligned}\text{Females: } \mathrm{METS} - \mathrm{VF} = {} & 4.466 + 0.011 \times (\mathrm{Ln}(\mathrm{METS} - \mathrm{IR}))^3 \\ & + 3.239 \times (\mathrm{Ln}(\mathrm{WHtR}))^3 + 0.319 \times 0 \\ & + 0.594 \times \mathrm{Ln}(\mathrm{age})\end{aligned} \tag{20}$$

$$\mathrm{CMI} = \frac{\mathrm{TG}}{\mathrm{HGL} - \mathrm{C}} \times \mathrm{WHtR} \tag{21}$$

Definition of covariates

The study employed a questionnaire devised by the Shandong Province's program for chronic disease risk factor surveillance. Metabolic equivalents (MET) of each physical activity of the population were assigned by the International Physical activity Questionnaire [40], and physical activity was categorized as low, medium, and high based on intensity, frequency, and total weekly activity. A resident's weekly level of physical activity was calculated as duration × frequency per week × MET intensity. Smoking was categorized into never-smoked, former smoker, and current smoker. Drinking was classified as never drinking, former drinker, and current drinker. Per the guidelines outlined in the 'Healthy China Initiative (2019–2030) [41], a daily sleep duration of 7 to 9 h is considered optimal for adults, signifying a low-risk sleep duration.

Statistical analysis

Non-normally distributed data were expressed as median (interquartile range), and the Kruskal-Walli's test was used to compare the differences between groups. Categorical data were presented as composition ratios or rates, and the Chi-square test was used for comparison. The ability of different anthropometric indices to predict Mets was evaluated by receiver operating characteristic (ROC) curve analysis and area under the curve values. Multivariate logistic analysis was carried out to estimate the correlation between anthropometric indices and the prevalence of MetS by quartiles of anthropometric indices. Besides the unadjusted model, two other models were developed. To evaluate the dose–effect correlations between anthropometric indices and MetS incidence, restricted cubic splines were employed.

Data were analyzed by SPSS 23.0 and R 4.1.2. With a significance level α set at 0.05, each test was conducted in two-sided.

Results

General characteristics of Chinese residents by sex group

2297 males and 3182 females were enrolled in the study. The differences observed in the prevalence of MetS, current residence, marital status, occupation, education status, income status, smoking, drinking, family history of chronic diseases, physical activity, BMI, WHtR, VAI, ABSI, BRI, LAP, CVAI, TyG index, TyG-BMI, TyG-WC, TyG-WHtR, WTI, AIP, METS-IR, METS-VF, and CMI, etc. were significant between the sexes ($p < 0.05$). These results are presented in Tables 1, 2 and 3. Given the notable differences between men and women, we performed the main analyses separately by gender.

Comparison of general characteristics between participants with MetS and without MetS

The study's participants were grouped by gender, allowing for a comparison of the demographic, behavioral, and clinical characteristics of MetS and non-MetS individuals within each gender group. Overall, statistically significant dis-parities ($p < 0.05$) were observed between individuals diagnosed with MetS and those without, including age, Current residence, marital status, occupation, level of education, income, smoking, and drinking, duration of low-risk sleep, familial history to chronic diseases, and patterns of physical exercise. These differences were significant across both genders, indicating that the MetS is affected by the involvement of multiple factors. It should be noted that, in comparison with non-MetS patients, MetS patients exhibit a markedly elevated level of anthropometric indicators, with a statistically significant difference ($p < 0.05$). These findings are presented in Tables 4, 5 and 6.

The capacity of anthropometric indices to predict the risk of metabolic syndrome in male and female populations

Tables 7 and 8 exhibit the predictive capability of anthropometric indices in assessing the risk of MetS across gender groups. The assessment metrics comprise the area under the curve (AUC), sensitivity, specificity, and their respective optimal cutoff points. The ROC curves for different indices to predict the prevalence of MetS among sexes are displayed in Fig. 2. In the male population, TyG-WHtR stands out as the most effective predictor of MetS, with an AUC of 0.907 (95%CI 0.895–0.919)

Table 1 Outcomes and outcome-related indicators of all study participants by gender

Characteristics	Male N (%)	Female N (%)	Overall N (%)	*P*
The prevalence of MetS	1105(48.1)	1391(43.7)	249(45.6)	0.001
WC (cm)	89.000 (81.000–97.000)	82.000 (71.925–91.000)	85.000 (76.000–94.000)	< 0.001
Weight (kg)	73.400 (66.000–81.750)	62.000 (56.900–69.400)	67.000 (59.000–75.000)	< 0.001
Height (cm)	170.000 (165.000–174.000)	158.500 (155.000–163.000)	163.000 (157.000–169.000)	< 0.001
TG (mg/dL)	124.889 (82.374–190.434)	107.174 (79.952–158.547)	113.375 (77.945–170.062)	< 0.001
TC (mg/dL)	194.122 (168.987–220.418)	197.602 (172.854–227.475)	195.669 (170.534–224.671)	0.001
HDL-C (mg/dL)	50.271 (43.310–59.551)	57.231 (49.111–66.222)	54.138 (46.404–64.192)	< 0.001
LDL-C (mg/dL)	119.490 (98.801–141.145)	117.169 (97.448–140.371)	117.943 (98.221–140.758)	< 0.001
FBG (mg/dL)	102.600 (93.600–117.000)	100.800 (93.600–113.400)	102.600 (93.600–115.200)	< 0.001
SBP (mmHg)	132.000 (120.000–143.000)	128.000 (115.00–143.000)	130.000 (118.000–142.000)	< 0.001
DBP (mmHg)	86.00 (78.00–93.00)	81.00 (74.00–89.00)	83.00 (75.00–91.00)	< 0.001

Continuous data are expressed as median (interquartile range) due to the skewed distribution

MetS Metabolic syndrome, *WC* waist circumference, *TC* total cholesterol, *TG* triglyceride, *HDL-C* high-density lipoprotein cholesterol, *LDL-C* low-density lipoprotein cholesterol, *FBG* fasting blood glucose, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *BMI* body mass index, *WHtR* waist to height ratio, *VAI* visceral adiposity index, *ABSI* A body shape index, *BRI*: body roundness index, *LAP* lipid accumulation product, *CI* Conicity Index, *CVAI* Chinese visceral adiposity index, *TyG* triglyceride, and glucose index, *TyG-BMI* TyG related to BMI, *TyG-WHtR* TyG related to WHtR, *TyG-WC* TyG related to wc, *WTI* waist-triglyceride index, *AIP cumulative* atherogenic index of plasma, *METS-IR* the metabolic score of insulin resistance, *METS-VF* Metabolism Score for Visceral Fat, *CMI* cardiometabolic index

and an optimal cut-off point of 4.5733. Additionally, TyG-WC and CVAI displayed comparable predictive capabilities. Among women, TyG-WHtR was also identified as the optimal predictor of MetS, with an AUC of 0.902(95%CI 0.891–0.912) and the optimal cut-off point of 4.4583, while TyG-WC exhibited a similar predictive performance. The AUC values for TyG-WHtR, TyG-WC, CVAI, LAP, and METS-VF exceeded 0.85 in both gender groups. As illustrated in Fig. 3, the values of TyG-WHtR, TyG-WC, CVAI, LAP, and METS-VF demonstrated a pattern of increasing with the accumulation of MetS components. Following a comprehensive evaluation of the AUC, sensitivity, and specificity, these five indices were selected as the most suitable for further analysis.

Multivariate logistic regression analyses of anthropometric indices and the prevalence of MetS

Three logistic regression models were employed to analyze the association between selected indices and the prevalence of MetS. The effect value of the model can be interpreted as with the increase in anthropometric indices, the probability of MetS prevalence increases correspondingly. As shown in Tables 9 and 10, five indices were taken as continuous variables separated into quartiles, with the first quartile (Q1) as the reference group. In the simple model, no covariates were adjusted; age was adjusted in model 1; variables that were meaningful on a one-way analysis in the baseline characteristics were adjusted in model 2.

In our analyses, among the male population, in the crude model, increasing levels of indices were significantly associated with the prevalence of MetS (p for trend < 0.05). However, in the fully adjusted model (Model 2), the prevalence of MetS increased dramatically with increasing levels of TyG-WC and METS-VF [TyG-WC at 4th quartile: Full adjusted Odds Ratio (OR) = 6.415, 95% confidence interval (CI) 2.011–20.467, p = 0.002; METS-VF at 4th quartile: Full adjusted OR = 3.580, 95%CI 1.498–8.551, p = 0.004 (Table 9)]. In contrast, the correlation between other indices and the prevalence of MetS was attenuated in Model 2 [CVAI at 2th quartile: Full adjusted OR = 1.849, 95% CI 0.994–3.437; p = 0.052; LAP at 2th quartile: Full adjusted OR = 1.781, 95% CI 0.962–3.297; p = 0.066; TyG-WHtR at 3th quartile: Full adjusted OR = 2.156, 95% CI 0.972–4.781; p = 0.059(Table 9)]. In conclusion, both TyG-WC and METS-VF maintained stable correlations with the prevalence of MetS after multivariable adjustment and may serve as superior anthropometric indices for predicting MetS in male populations.

Among the female population, in the crude model, increasing levels of indices were significantly associated with the prevalence of MetS (p for trend < 0.05). However, in Model 2, the prevalence of MetS did not differ observably at different levels of CVAI (p for trend = 0.827). Though the prevalence of MetS rates rose as TyG-WC、LAP and TyG-WHtR increased (p for trend < 0.005), TyG-WHtR showed instability in its relationship with the prevalence of MetS [TyG-WHtR at 2th quartile: Full adjusted OR = 1.966, 95% CI 0.903–4.280, p = 0.089 (Table 10)]. Similarly, Significant differences in TyG-WC and LAP were observed only in the fourth

Table 2 General characteristics of all study participants by gender

Characteristics	Male N (%)	Female N (%)	Overall N (%)	*P*
Age, years	52.0 (39.0–61.0)	52.0 (40.0–60.0)	52.0 (40.0–60.0)	0.195
Current residence				
Rural	750 (32.7)	1152 (36.2)	1902 (44.7)	0.006
Urban	1547 (67.4)	2030 (63.8)	3577 (65.3)	
Marital status				
Single/widowed/divorced	303 (13.2)	264 (8.3)	567 (10.4)	< 0.001
Others	1994 (86.8)	2917 (91.7)	4911 (89.7)	
Occupation				
Agriculture, forestry, animal husbandry, fishery and personnel	1345 (58.6)	1424 (44.8)	2769 (50.5)	< 0.001
Manufacturer, transport and salesperson	155 (6.8)	162 (5.1)	317 (5.8)	
Government and enterprise workers	168 (7.3)	158 (5.0)	326 (6.0)	
Other occupation	350 (15.2)	422 (13.3)	772 (14.1)	
Unemployed/students/retiree	279 (12.2)	1016 (31.9)	1295 (23.6)	
Education status				
Below primary school	725 (31.6)	1295 (40.7)	2020 (36.0)	< 0.001
Junior middle school	990 (43.1)	1152 (36.2)	2142 (39.1)	
High school or Specialized Secondary Schools	391 (17.0)	360 (11.3)	751 (13.7)	
College and above	191 (8.3)	375 (11.8)	566 (10.3)	
Income status				
< 1500	507 (22.1)	699(22.0)	1206(22.0)	< 0.001
1500 ~	623 (27.1)	1032(32.4)	1655(30.2)	
3500 ~	1166 (50.8)	1451(45.6)	2617(47.8)	
Smoking				
Never	825 (35.9)	2810 (88.3)	3635 (67.3)	< 0.001
Former smoker	160 (7.0)	43 (1.4)	203 (3.7)	
Current	1312 (57.1)	329 (10.3)	1641 (30.0)	
Drinking				
Never	549 (23.9)	2071 (76.1)	2620 (47.8)	< 0.001
Former drinker	227 (9.9)	78 (2.5)	305 (5.6)	
Current	1521 (66.2)	1033 (32.5)	2554 (46.6)	
Sleep duration of low risk				
Yes	1943 (41.7)	2709 (58.2)	4652 (84.9)	0.577
No	354 (15.4)	473 (57.2)	827 (15.1)	
Family history of chronic diseases				
0	1364 (59.4)	1480 (46.5)	2844 (51.9)	< 0.001
1–2	579 (25.2)	1163 (36.5)	1742 (31.8)	
≥ 3	354 (15.4)	539 (16.9)	893 (16.3)	
Physical activity				
Low	1620 (70.5)	2175 (68.4)	3795 (69.3)	< 0.001
Middle	308 (13.4)	562 (17.7)	870 (15.9)	
High	369 (16.1)	445 (13.00)	814 (14.9)	

Continuous data are expressed as median (interquartile range) due to the skewed distribution

quartile (Q4) compared to the reference group(Q1) [TyG-WC at 4th quartile: Full adjusted OR = 3.306, 95% CI 1.071–8.606, $p = 0.037$; LAP at 4th quartile: Full adjusted OR = 5.697, 95% CI 2.402–13.512, $p < 0.001$ (Table 10)]. Compared with these indices, the positive correlation between METS-VF and the prevalence of MetS remained [METS-VF at 4th quartile: Full adjusted OR = 7.615, 95% CI 3.588–16.164, $p < 0.001$ (Table 10)].

Table 3 Anthropometric indices of all study participants by gender

Characteristics	Male $M(P_{25}\text{-}P_{75})$	Female $M(P_{25}\text{-}P_{75})$	Overall $M(P_{25}\text{-}P_{75})$	*P*
BMI	25.565 (23.301–27.916)	24.768 (22.547–27.556)	25.100 (22.837–27.745)	< 0.001
WHtR	0.525 (0.471–0.571)	0.516 (0.439–0.575)	0.519 (0.459–0.573)	< 0.001
VAI	1.357 (0.830–2.388)	1.474 (0.946–2.448)	1.439 (0.896–2.418)	< 0.001
ABSI	0.079 (0.075–0.083)	0.077 (0.072–0.082)	0.078 (0.073–0.083)	< 0.001
BRI	3.832 (2.839–4.797)	3.665 (2.278–4.874)	3.722 (2.615–4.838)	< 0.001
LAP	32.508 (17.591–58.800)	27.297 (14.820–49.600)	29.623 (15.984–53.613)	< 0.001
CI	7.162 (6.709–7.533)	6.927 (6.366–7.406)	7.038 (6.505–7.468)	< 0.001
CVAI	103.283 (68.921–139.771)	87.480 (56.817–116.406)	92.992 (62.005–126.459)	< 0.001
TyG Index	8.789 (8.347–9.282)	8.635 (8.237–9.082)	8.689 (8.280–9.163)	< 0.001
TyG-BMI	225.736 (200.005–255.113)	215.605 (189.690–254.488)	220.329 (193.920–249.769)	< 0.001
TyG-WHtR	4.628 (4.121–5.180)	4.437 (3.864–5.102)	4.533 (3.968–5.138)	< 0.001
TyG-WC	782.339 (696.479–875.901)	704.964 (616.339–803.954)	739.609 (648.917–837.484)	< 0.001
WTI	8.386 (7.992–8.812)	8.613 (8.173–9.074)	8.480 (8.074–8.932)	< 0.001
AIP	0.028 (– 0.192–0.264)	– 0.090 (– 0.279–0.121)	– 0.045 (– 0.243–0.180)	< 0.001
METS-IR	38.498 (33.514–43.757)	35.794 (31.320–40.890)	36.984 (32.144–42.275)	< 0.001
METS-VF	6.742 (6.214–7.130)	6.307 (5.528–6,827)	6.497 (5.876–6.972)	< 0.001
CMI	0.560 (0.330–0.988)	0.418 (0.262–0.713)	0.467 (0.287–0.830)	< 0.001

Continuous data are expressed as median (interquartile range) due to the skewed distribution

Table 4 Outcome-related indicators of study participants with and without MetS by sex groups

Characteristics	Males (N = 2297)		*P*	Females (N = 3182)		*P*
	MetS $M(P_{25}\text{-}P_{75})$	Non-MetS $M(P_{25}\text{-}P_{75})$		MetS $M(P_{25}\text{-}P_{75})$	Non-MetS $M(P_{25}\text{-}P_{75})$	
WC (cm)	83.000 (77.000–87.600)	96.000 (90.00–102.000)	< 0.001	90.000 (84.000–96.000)	74.000 (68.775–82.000)	< 0.001
Weight (kg)	78.000 (71.600–85.000)	69.000 (62.80–76.000)	< 0.001	65.100 (60.000–73.000)	60.000 (55.000–66.000)	< 0.001
Height (cm)	170.000 (165.000–174.000)	169.500 (165.00–174.00)	< 0.001	158.000 (158.000–162.000)	159.000 (155.000–163.500)	< 0.001
TC (mg/dL)	166.519 (107.174–247.678)	99.203 (72.631–138.175)	< 0.001	88.574 (67.316–120.461)	150.576 (99.203–211.692)	< 0.001
TG (mg/dL)	199.923 (174.787–229.312)	188.322 (165.120–214.230)	< 0.001	208.817 (180.201–237.046)	191.029 (167.440–217.324)	< 0.001
HDL-C (mg/dL)	46.790 (39.830–54.911)	53.751 (46.404–63.032)	< 0.001	52.591 (45.630–61.872)	60.325 (52.978–69.606)	< 0.001
LDL-C (mg/dL)	123.163 (102.088–147.718)	115.623 (96.674–135.731)	< 0.001	125.677 (103.248–148.105)	113.369 (93.194–133.411)	< 0.001
FBG (mg/dL)	109.800 (100.800–122.400)	97.200 (91.800–109.800)	< 0.001	108.000 (100.800–122.400)	97.200 (91.800–106.200)	< 0.001
SBP (mmHg)	137.000 (128.000–149.000)	126.000 (116.000–137.000)	< 0.001	137.000 (125.000–151.000)	97.200 (91.800–106.200)	< 0.001
DBP (mmHg)	89.000 (82.000–97.000)	82.000 (75.000–90.000)	< 0.001	85.000 (78.000–93.000)	78.000 (72.000–86.000)	< 0.001

Non-linear trends of anthropometric indices with morbidity of MetS

Figure 4 represents the dose–response relationship between indices and MetS risk. This study employed a restricted cubic spline model integrated with logistic regression to fit smooth curves depicting the association between indices and MetS risk. Based on the results of multivariate logistic regression, METS-VF and TyG-WC were selected as predictors in the male population, while METS-VF alone was selected in the female population. Based on the adjusted model 2, a nonlinear positive correlation was observed between METS-VF and MetS risk in both sexes (nonlinear $p < 0.001$). Specifically, among females, a threshold of 6.32 for METS-VF was identified above which the risk of MetS may increase. Similarly, in males, a threshold of 6.74 for METS-VF was found to potentially elevate MetS risk. Additionally, this study observed a nonlinear relationship between TyG-WC and MetS risk in males (nonlinear p significant). Specifically, when TyG-WC exceeded 583.71, the risk of MetS in males appeared to increase.

Table 5 General Characteristics of study participants with and without MetS by sex groups

Characteristics	Males (N = 2297)		*P*	Females (N = 3182)		*P*
	MetS N (%)	Non-MetS N (%)		MetS N (%)	Non-MetS N (%)	
Age, years	54.0 (43.0–61.0)	49.0 (35.0–61.0)	< 0.001	57.0 (48.0–62.0)	47.0 (36.0–56.0)	< 0.001
Current residence						
Rural	399 (32.7)	351 (29.4)	0.001	548 (39.4)	604 (33.7)	0.001
Urban	706 (63.9)	841 (70.6)		843 (60.6)	1187 (66.3)	
Marital status						
Single/widowed/divorced	88 (8.0)	215 (18.0)	< 0.001	86 (6.2)	178 (9.9)	< 0.001
Others	1017 (92.0)	977 (82.0)		1304 (93.8)	1613 (90.1)	
Occupation						
Agriculture, forestry, animal husbandry, fishery and personnel	699 (62.3)	657 (55.1)	0.012	685 (49.2)	739 (41.3)	< 0.001
Manufacturer, transport and salesperson	70 (6.3)	85 (7.1)		57 (4.1)	105 (5.9)	
Government and enterprise workers	74 (6.7)	94 (7.9)		36 (2.6)	122 (6.8)	
Other occupation	157 (14.2)	193 (16.2)		159 (11.4)	263 (14.7)	
Unemployed/students/retiree	116 (10.5)	163 (13.7)		454 (32.6)	562 (31.4)	
Education level						
Below primary school	403 (36.5)	322 (27.0)	< 0.001	752 (54.1)	637 (35.6)	< 0.001
Junior middle school	478 (43.3)	512 (43.0)		463 (33.3)	689 (38.5)	
High school or Specialized Secondary Schools	161 (14.6)	230 (19.3)		114 (8.2)	246 (13.7)	
College and above	63 (5.7)	128 (10.7)		62 (4.5)	219 (12.2)	
Income status						
< 1500	243 (22.0)	264 (22.2)	0.006	269 (22.0)	430 (24.0)	< 0.001
1500 ~	268 (24.3)	355 (29.8)		1032 (32.4)	607 (33.9)	
3500 ~	594 (53.8)	572 (48.0)		1451 (45.6)	754 (42.1)	
Smoking						
Never	319 (35.9)	506 (42.4)	< 0.001	1169 (84.0)	1694 (94.6)	< 0.001
Former smoker	84 (7.6)	76 (6.4)		22 (1.6)	21 (1.2)	
Current	702 (63.5)	610 (51.2)		200 (14.4)	76 (4.2)	
Drinking						
Never	192 (23.9)	357 (29.9)	< 0.001	823 (59.2)	1605 (89.6)	< 0.001
Former drinker	94 (8.5)	133 (11.2)		27 (1.9)	51 (2.8)	
Current	819 (74.1)	702 (58.9)		1391 (38.9)	135 (7.5)	
Sleep duration of low risk						
Yes	917 (83.0)	1026 (86.1)	0.041	1162 (83.5)	1547 (86.4)	0.026
No	188 (17.0)	166 (13.9)		229 (16.5)	244 (13.6)	
Family history of chronic diseases						
0	598 (54.1)	766 (64.3)	0.001	600 (43.1)	880 (49.1)	< 0.001
1–2	324 (29.3)	255 (21.4)		498 (35.8)	665 (37.1)	
≥3	183 (16.6)	171 (14.3)		293 (21.1)	246 (13.7)	
Physical activity						
Low	822 (74.4)	798 (66.9)	< 0.001	1142 (63.8)	1033 (74.3)	< 0.001
Middle	148 (13.5)	159 (13.3)		369 (20.6)	193 (13.9)	
High	134 (12.1)	235 (19.7)		280 (15.6)	165 (11.9)	

Continuous data are expressed as median (interquartile range) due to the skewed distribution

Table 6 Anthropometric indices of study participants with and without MetS by sex groups

Characteristics	Males (N = 2297)		*P*	Females (N = 3182)		*P*
	MetS M(P_{25}-P_{75})	Non-MetS M(P_{25}-P_{75})		MetS M(P_{25}-P_{75})	Non-MetS M(P_{25}-P_{75})	
BMI	27.059 (24.963–29.277)	24.10 (21.97–26.30)	< 0.001	26.330 (24.142–29.049)	23.606 (21.454–25.965)	< 0.001
WHTR	0.567 (0.532–0.601)	0.483 (0.456–0.521)	< 0.001	0.571 (0.527–0.611)	0.463 (0.432–0.516)	< 0.001
VAI	2.080 (1.253–3.515)	0.981 (0.656–1.522)	< 0.001	2.314 (1.444–3.655)	1.121 (0.779–1.639)	< 0.001
ABSI	0.082 (0.078–0.085)	0.077 (0.073–0.081)	< 0.001	0.080 (0.076–0.085)	0.074 (0.068–0.079)	< 0.001
BRI	4.704 (3.982–5.454)	3.045 (2.575–3.762)	< 0.001	4.797 (3.878–5.670)	2.691 (2.171–3.666)	< 0.001
LAP	55.680 (35.818–88.015)	18.720 (11.692–31.588)	< 0.001	49.980 (32.592–78.000)	16.950 (10.021–26.910)	< 0.001
CI	7.444 (7.147–7.773)	6.869 (6.466–7.212)	< 0.001	7.309 (6.942–7.688)	6.556 (6.006–7.021)	< 0.001
CVAI	138.002 (113.082–164.755)	72.877 (51.855–95.530)	< 0.001	115.356 (93.748–137.398)	63.319 (38.331–88.396)	< 0.001
TyG	9.125 (8.665–9.599)	8.514 (8.181–8.876)	< 0.001	9.013 (8.621–9.442)	8.407 (8.087–8.723)	< 0.001
TyG-BMI	247.289 (224.765–273.833)	206.231 (183.290–228.447)	< 0.001	238.735 (215.451–265.597)	198.335 (177.927–223.351)	< 0.001
TyG-WC	870.5187 (813.811–950.422)	703.903 (653.506–760.782)	< 0.001	806.748 (742.471–880.057)	630.256 (578.031–692.033)	< 0.001
TyG-WHtR	5.163 (4.764–5.571)	4.161 (3.865–4.516)	< 0.001	5.118 (4.681–5.604)	3.939 (3.637–4.353)	< 0.001
WTI	8.973 (8.574–9.383)	8.310 (7.976–8.673)	< 0.001	8.793 (8.416–9.142)	8.134 (7.838–8.451)	< 0.001
AIP	0.187 (− 0.039–0.406)	− 0.105 (− 0.270–0.080)	< 0.001	0.086 (− 0.134–0.288)	− 0.195 (− 0.351–0.031)	< 0.001
MET-IR	42.495 (38.138–47.219)	34.684 (30.693–39.132)	< 0.001	39.750 (35.894–44.521)	32.774 (29.127–36.802)	< 0.001
METS-VF	7.094 (6.821–7.319)	6.284 (5.990–6.684)	< 0.001	6.820 (6.443–7.047)	5.647 (5.309–6.280)	< 0.001
CMI	0.870 (0.525–1.455)	0.383 (0.258–0.604)	< 0.001	0.691 (0.422–7.047)	0.307 (0.212–0.456)	< 0.001

Table 7 ROC analysis of anthropometric indices among males for identifying MetS

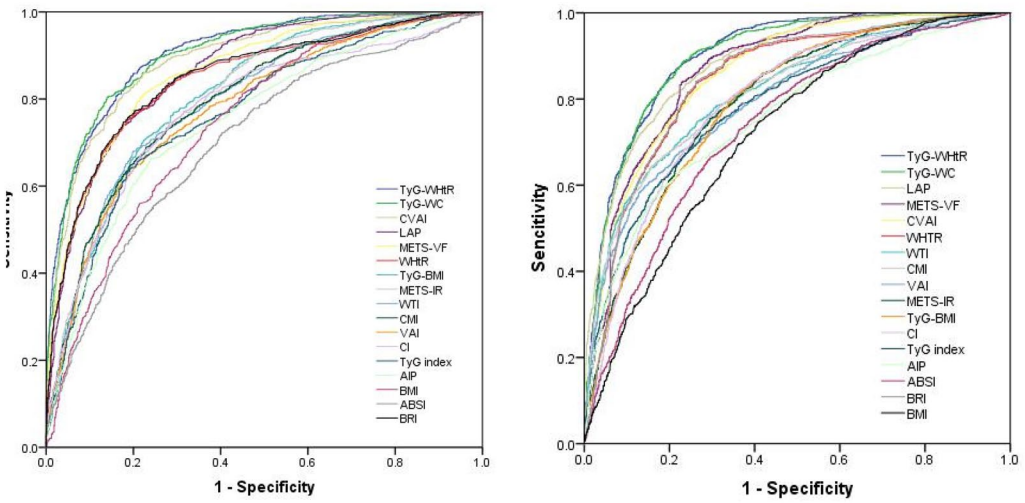
Anthropometric index	AUC	95%CI	Cut-off point	Sensitivity (%)	Specificity (%)
TyG-WHtR	0.907	0.895–0.919	4.5733	87.34	78.51
TyG-WC	0.905	0.892–0.916	795.2513	80.38	86.06
CVAI	0.890	0.877–0.903	98.4569	85.99	77.58
LAP	0.865	0.850–0.879	36.7400	73.96	82.28
METS-VF	0.864	0.849–0.877	6.7241	81.37	77.41
BRI	0.850	0.834–0.864	0.5284	77.31	79.76
WHtR	0.845	0.829–0.859	0.5284	76.76	79.76
TyG-BMI	0.810	0.793–0.826	230.3135	70.61	77.58
METS-IR	0.806	0.789–0.822	38.4247	74.50	71.79
WTI	0.796	0.779–0.812	8.7323	67.90	80.18
CMI	0.796	0.779–0.812	0.6166	68.99	77.08
VAI	0.780	0.762–0.797	1.6294	64.92	79.26
CI	0.778	0.761–0.795	7.1430	75.05	70.61
TyG index	0.767	0.749–0.784	8.9469	64.01	80.77
AIP	0.752	0.734–0.770	0.0804	66.37	75.99
BMI	0.747	0.728–0.764	25.1000	73.78	63.14
ABSI	0.706	0.687–0.724	0.0786	72.24	59.61

Discussion

This study examined 17 anthropometric indices associated with MetS and its components to assess their predictive abilities for MetS in Chinese residents. In this study of 5479 residents, the prevalence of MetS was 48.1% among men and 43.7% among women. In the analysis of the demographic characteristics of the entire sample, the results showed that all the indices included were closely related to the occurrence of MetS. After considering the results of the ROC analysis, TyG-WHtR, TyG-WC, LAP, METS-VF, and CVAI were selected for further research to evaluate their correlation with the risk of MetS. The study suggested that TyG-WC and METS-VF had greater predictive abilities in the males, with TyG-WC appearing

Table 8 ROC analysis of anthropometric indices among females for identifying MetS

Anthropometric index	AUC	95%CI	Cut-off point	Sensitivity (%)	Specificity (%)
TyG-WHtR	0.902	0.891–0.912	4.4582	85.98	79.56
TyG-WC	0.899	0.888–0.909	697.7630	88.71	76.77
LAP	0.886	0.875–0.897	29.7190	80.37	80.12
METS-VF	0.869	0.857–0.881	6.3179	83.96	77.11
CVAI	0.862	0.849–0.874	87.4904	81.45	74.48
BRI	0.845	0.832–0.858	3.5876	84.11	73.76
WHtR	0.841	0.828–0.854	0.5120	83.68	73.76
WTI	0.817	0.803–0.830	8.5930	64.13	84.25
CMI	0.814	0.800–0.827	0.5235	65.71	82.91
VAI	0.797	0.782–0.810	1.9837	59.81	85.82
METS-IR	0.792	0.778–0.806	35.865	75.51	70.46
CI	0.791	0.777–0.805	6.9286	76.04	70.63
TyG-BMI	0.791	0.777–0.805	210.5545	80.88	64.66
TyG-index	0.785	0.770–0.799	8.6822	71.39	72.64
AIP	0.760	0.744–0.744	0.0162	59.60	81.41
ABSI	0.737	0.721–0.752	0.0777	66.62	70.30
BMI	0.718	0.702–0.734	24.1671	74.62	59.07



(**a**) (**b**)

Fig. 2 ROC curves for 17 anthropometric indices for identifying MetS among males (**a**), and females (**b**)

as a more useful indication than METS-VF. Meanwhile, in women, METS-VF outperformed all other indicators. This revealed that the best predictors of MetS differ between the sexes.

MetS is not simply a biological problem, but a complex social issue linked to unhealthy lifestyles [42, 43]. This study suggests that MetS risk factors are multifaceted [44], such as age, sex [45], occupation, smoking, drinking [46], physical activity [47, 48], and history of disease [49]. This finding aligns with previous researchers' studies. Moreover, these factors notably affected the anthropometric index's predictive power. In the analysis of the ROC curve, the AUC values for TyG-WHtR, TyG-WC, LAP, METS-VF, and CVAI were all greater than 0.850. However, after adjusting for all confounding factors in Model 2, METS-VF and TyG-WC were substantially linked with the risk of MetS in males, while only METS-VF showed a connection in females. This implies that the standard for evaluating the predictive accuracy of an index cannot be based on the outcome of ROC analysis

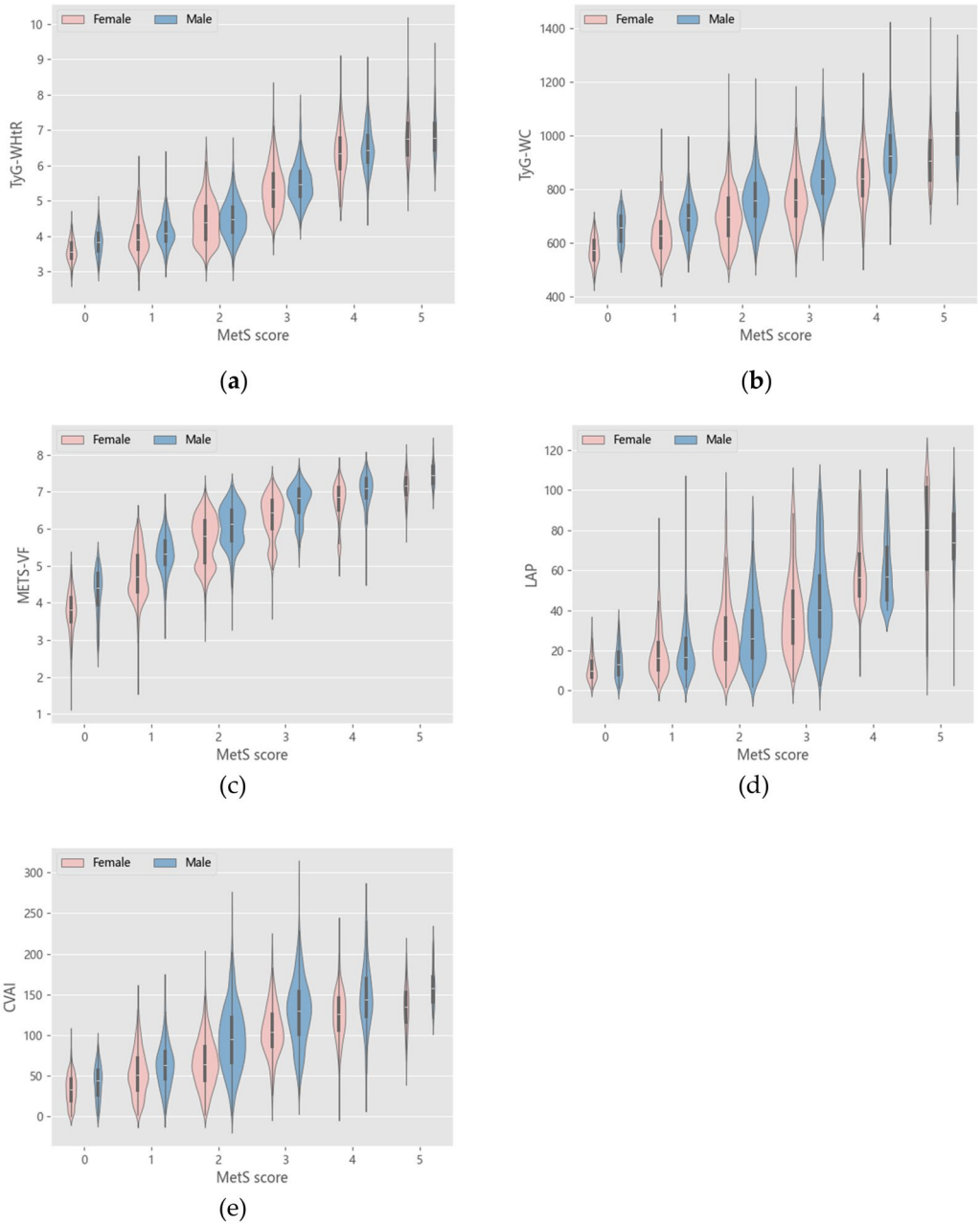


Fig. 3 Distribution of the values of TyG-WHtR (**a**), TyG-WC (**b**), METS-VF (**c**), LAP (**d**), CVAI (**e**) according to the number of components of MetS

but also on the influence of confounding factors in practical applications.

In this research, METS-VF was found to be a good predictor of the prevalence of MetS among men and women, and it is especially valuable in the female population, outperforming other indices. The METS-VF calculation includes several metabolic-related parameters, such as fasting blood glucose, triglycerides, and high-density lipoprotein cholesterol, which collectively reflect an individual's metabolic health status. By calculating METS-VF, physicians can assess a patient's visceral fat metabolism and determine whether they have metabolic abnormalities or are at risk of disease. This is important for formulating a personalized diet and exercise plan and preventing metabolic diseases. Ruijuan Y et al. indicated that METS-VF [14], as a new indicator for assessing abdominal and visceral fat, is valuable in predicting chronic disease [50, 51]. Based on the ROC

Table 9 Multivariable logistic regression of anthropometric indices and the prevalence of MetS in male

Anthropometric index	Crude model OR (95%CI)	*p*	Model 1 OR (95%CI)	*p*	Model 2 OR (95%CI)	*p*
TyG-WHtR						
Q1	Ref		Ref		Ref	
Q2	1.307(0.683–2.502)	0.419	1.341(0.699–2.570)	0.377	1.388(0.71–2.713)	0.338
Q3	2.11(0.981–4.538)	0.056	2.223(1.031–4.794)	0.042	2.156(0.972–4.781)	0.059
Q4	5.133(1.873–14.066)	0.001	5.563(2.020–15.322)	0.001	5.254(1.85–14.932)	0.002
P for trend	< 0.001		< 0.001		< 0.001	
TyG-WC						
Q1	Ref		Ref		Ref	
Q2	3.491(1.584–7.694)	0.002	3.734(1.697–8.219)	0.001	3.994(1.785–8.938)	0.001
Q3	5.228(2.100–13.016)	< 0.001	6.017(2.404–15.059)	< 0.001	6.162(2.410–15.756)	< 0.001
Q4	5.345(1.750–16.325)	0.003	6.636(2.143–20.554)	0.001	6.415(2.011–20.467)	0.002
P for trend	0.003		0.001		0.003	
CVAI						
Q1	Ref		Ref		Ref	
Q2	1.840(1,003–3.377)	0.049	1.906(1.041–3.491)	0.037	1.849(0.994–3.437)	0.052
Q3	2.361(1.148–4.857)	0.020	2.523(1.227–5.188)	0.012	2.621(1.241–5.535)	0.012
Q4	3.606(1.491–8.722)	0.004	3.982(1.643–9.647)	0.002	4.503(1.621–10.133)	0.003
P for trend	0.008		0.005		0.004	
LAP						
Q1	Ref		Ref		Ref	
Q2	1.873(1.026–3.416)	0.041	1.917(1.054–3.484)	0.033	1.781(0.962–3.297)	0.066
Q3	1.984(0.999–3.940)	0.050	2.008(1.013–3.980)	0.046	2.044(1.008–4.143)	0.047
Q4	3.787(1.676–8.557)	0.001	3.756(1.666–8.466)	0.001	3.940(1.695–9.161)	0.001
P for trend	0.005		0.006		0.005	
METS-VF						
Q1	Ref		Ref		Ref	
Q2	2.297(1.385–3.812)	0.001	1.920(1.139–3.236)	0.014	1.806(1.055–3.092)	0.031
Q3	3.215(1.759–5.877)	< 0.001	2.295(1.195–4.406)	0.013	2.070(1.054–4.064)	0.035
Q4	5.621(2.637–11.981)	< 0.001	3.433(1.482–7.952)	0.004	3.580(1.498–8.551)	0.004
P for trend	< 0.001		0.003		0.005	

analysis, METS-VF showed a great predictive capacity in the male and female populations respectively. This is similar to the results of a Spanish study in which the AUC values for METS-VF were 0.838 and 0.883 [52]. Meanwhile, this study indicated an increasing level of METS-VF with increasing components of MetS. Multifactorial logistic regression analysis suggested an increased risk of MetS with increasing METS-VF. According to the crude model and adjusted models, the close correlation always remained. Our research showed a non-linear, positive dose–response relationship between METS-VF and the prevalence of MetS in the sexes. Specifically, When it exceeds 6.32 in women and 6.7 in men, the risk of MetS markedly increases.

Although METS-VF performed well in the overall population, TyG-WC performed better than METS-VF in the male population. The use of TyG-WC as a predictor of diseases is gaining prominence in previous studies [53], especially for heart disease [54], which is superior to other TyG indices to a certain extent. In the present study, TyG-WC showed high AUC values (0.905, 0.899) in both gender groups, mirroring the outcomes observed in previous studies [20, 22]. However, following the subsequent multivariate regression analysis, which accounted for confounding factors such as age, smoking, alcohol consumption, physical activity, and family history in the female group, the significance of the association between TyG-WC and MetS risk was no longer present ($p > 0.05$), whereas this association persisted in men. Furthermore, the RCS curve found that in the male population, there is a non-linear positive correlation between TyG-WC and MetS.This finding indicates that while TyG-WC has a commendable predictive capacity, it may not be ideal for application across the entire population. Given the

Table 10 Multivariable logistic regression of anthropometric indices and the prevalence of MetS in female

Anthropometric index	Crude model OR (95%CI)	*p*	Model 1 OR (95%CI)	*p*	Model 2 OR (95%CI)	*p*
TyG-WHtR						
Q1	Ref		Ref		Ref	
Q2	2.322(1.126–4.787)	0.022	2.407(1.164–4.977)	0.018	1.966(0.903–4.280)	0.089
Q3	3.348(1.453–7.711)	0.005	3.497(1.513–8.083)	0.003	2.845(1.444–7.703)	0.024
Q4	4.957(1.759–12.018)	0.002	5.001(1.906–13.125)	0.001	4.040(1.423–11.472)	0.009
P for trend	0.040		0.024		0.037	
TyG-WC						
Q1	Ref		Ref		Ref	
Q2	1.590(0.991–3.282)	0.209	1.637(0.792–3.384)	0.183	1.251(0.558–2.805)	0.587
Q3	3.008(1.329–6.805)	0.008	3.497(1.535–7.791)	0.003	2.354(0.940–5.898)	0.068
Q4	4.012(1.585–10.156)	0.003	5.079(1.979–13.037)	0.001	3.036(1.071–8.606)	0.037
P for trend	< 0.001		< 0.001		0.006	
LAP						
Q1	Ref		Ref		Ref	
Q2	2.020(1.055–3.870)	0.034	2.112(1.101–4.051)	0.024	1.942(0.957–3.941)	0.066
Q3	2.161(1.070–4.364)	0.032	2.353(1.162–4.767)	0.017	1.862(0.859–4.036)	0.115
Q4	5.210(3.178–9.119)	< 0.001	5.974(2.736–13.044)	< 0.001	5.697(2.402–13.512)	< 0.001
P for trend	< 0.001		< 0.001		< 0.001	
METS-VF						
Q1	Ref		Ref		Ref	
Q2	2.297(1.420–3.714)	0.001	2.1415(1.325–4.474)	0.002	3.374(1.991–5.717)	< 0.001
Q3	4.535(2.942–6.992)	0.001	2.353(1.355–4.085)	0.002	5.251(2.836–9.721)	< 0.001
Q4	5.310(2.444–11.538)	< 0.001	2.929(1.487–5.768)	0.002	7.615(3.588–16.164)	< 0.001
P for trend	< 0.001		< 0.001		< 0.001	
CVAI						
Q1	Ref		Ref		Ref	
Q2	2.743(1.817–4.140)	< 0.001	2.052(1.312–3.209)	0.002	1.789(1.093–2.926)	0.021
Q3	4.535(2.942–6.992)	< 0.001	2.790(1.657–4.697)	< 0.001	1.762(0.986–3.148)	0.056
Q4	5.383(3.178–9.119)	< 0.001	2.858(1.494–5.470)	0.002	1.384(0.677–2.827)	0.373
P for trend	< 0.001		0.025		0.827	

complex interaction of genetic background, lifestyle, physiological characteristics, and psychosocial factors that affect MetS, and the significant differences between men and women in these factors, it is essential to consider gender differences when developing prevention and treatment strategies for metabolic syndrome. In conclusion, the findings of this study indicate that the METS-VF is a reliable predictor of MetS in Chinese residents. However, from the perspective of gender differences, this study emphasizes the critical need for the early detection of MetS using different indicators for men and women.

The present study had several notable advantages: Firstly, this study extensively examines a diverse range of MetS prediction indices, encompassing 17 anthropometric indicators. It not only evaluates their capacity to predict MetS but also conducts an in-depth exploration of the stability of these indices in forecasting MetS, thereby offering a thorough analysis of their prediction performance. Secondly, this study involves a sample size of 5479 residents, contributing to the dependability of the results. Furthermore, this study offers a comprehensive gender-specific analysis, intending to identify the most accurate predictive index for each gender. Nevertheless, the study had limitations. It is hard to validate a temporal relationship between anthropometric indices and MetS because of the cross-sectional. Furthermore, as only Chinese residents were involved, although it is highly relevant and applicable in the Chinese context, the reliable indices selected in this study may not apply to other populations. Therefore, in order to further elucidate the causal relationship between anthropometric indices and MetS, future research needs to adopt a cohort study design to further verify and extend these findings.

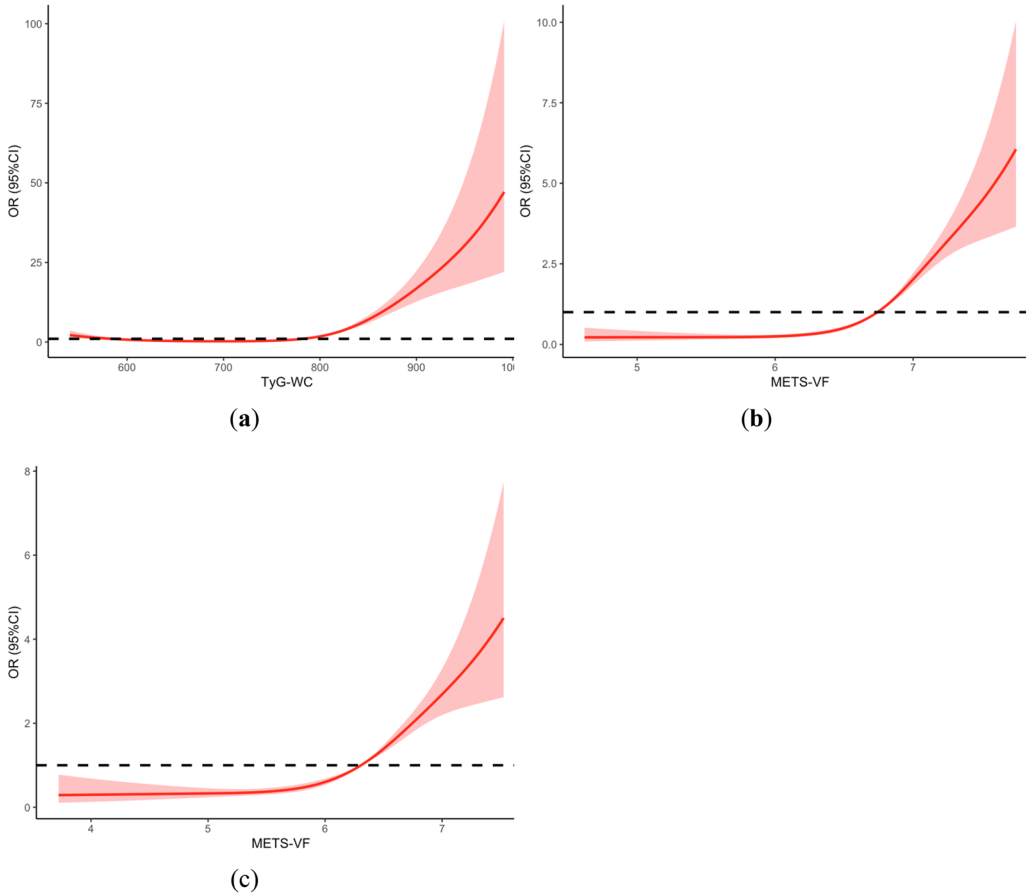


Fig. 4 Dose–response relationship between MetS risk and anthropometric indices among males and females. **a**: MetS risk with different levels of the TyG-WC in males **b**: MetS risk with different levels of the METS-VF in males, **c**: MetS risk with different levels of the METS-VF in females

Conclusion

Anthropometric indices could serve as an effective tool for evaluating the prevalence of MetS among Chinese residents. Our study demonstrates that for males, both TyG-WC and METS-VF display comparable predictive power. Conversely, for females, METS-VF stands out as the optimal predictive indicator.

Abbreviations

MetS	Metabolic syndrome
WC	Waist circumference
TC	Total cholesterol
TG	Triglyceride
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
FBG	Fasting blood glucose
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
BMI	Body mass index
WHtR	Waist to height ratio
VAI	Visceral adiposity index
ABSI	A body shape index
BRI	Body roundness index
LAP	Lipid accumulation product
CI	Conicity index
CVAI	Chinese visceral adiposity index
TyG	Triglyceride, and glucose index
TyG-BMI	TyG related to BMI
TyG-WHtR	TyG related to WHtR
TyG-WC	TyG related to wc
WTI	Waist-triglyceride index
AIP	Cumulative atherogenic index of plasma
METS-IR	The metabolic score of insulin resistance
METS-VF	Metabolism score for visceral fat
CMI	Cardiometabolic index

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Author contributions

Study design, W.W., J.Z., P.Z., and W.L.; methodology, P.Z., W.L; validation, P.Z., W.L.; data analysis, P.Z., W.L., and K.S.; investigation, P.Z., W.L., K.S., Z.Z., and W.Z.; data curation, P.Z., W.L., K.S., Z.Z., and W.Z.; writing—original draft preparation, P.Z. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study received approval from the Ethics Committee of the North China University of Science and Technology (No. 16040). Informed consent was obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Cornier M-A, Dabelea D, Hernandez TL, et al. The metabolic syndrome. Endocr Rev. 2008;29(7):777–822.
2. Guembe MJ, Fernandez-Lazaro CI, Sayon-Orea C, et al. Risk for cardiovascular disease associated with metabolic syndrome and its components: a 13-year prospective study in the RIVANA cohort. Cardiovasc Diabetol. 2020;19(1):195.
3. Li M, Cao SM, Dimou N, et al. Association of metabolic syndrome with risk of lung cancer: a population-based prospective cohort study. Chest. 2024;165(1):213–23.
4. Grundy SM. Metabolic syndrome pandemic. Arterioscler Thromb Vasc Biol. 2008;28(4):629–36.
5. Hossain P, Kawar B, El Nahas M. Obesity and diabetes in the developing world–a growing challenge. N Engl J Med. 2007;356(3):213–5.
6. Noubiap JJ, Nansseu JR, Lontchi-Yimagou E, et al. Global, regional, and country estimates of metabolic syndrome burden in children and adolescents in 2020: a systematic review and modelling analysis. Lancet Child Adolesc Health. 2022;6(3):158–70.
7. Cheng X, Guo Q, Ju L, et al. Association between sedentary behavior, screen time and metabolic syndrome among Chinese children and adolescents. BMC Pub Health. 2024;24(1):1715.
8. Chen Y, Xu W, Zhang W, et al. Plasma metabolic fingerprints for large-scale screening and personalized risk stratification of metabolic syndrome. Cell Rep Med. 2023;4(7):101109.
9. Simmons RK, Alberti KG, Gale EA, et al. The metabolic syndrome: useful concept or clinical tool? Report of a WHO expert consultation. Diabetologia. 2010;53(4):600–5.
10. Gallagher EJ, Leroith D, Karnieli E. Insulin resistance in obesity as the underlying cause for the metabolic syndrome. Mt Sinai J Med. 2010;77(5):511–23.
11. Cornier M-A, Després J-P, Davis N, et al. Assessing adiposity. Circulation. 2011;124(18):1996–2019.
12. Li Y, Yu D, Yang Y, et al. Comparison of several adiposity indexes in predicting hypertension among Chinese adults: data from china nutrition and health surveillance (2015–2017). Nutrients. 2023;15(9):2146.
13. Tamini S, Bondesan A, Caroli D, Sartorio A. The lipid accumulation product index (LAP) and the cardiometabolic index (CMI) are useful for predicting the presence and severity of metabolic syndrome in adult patients with obesity. J Clin Med. 2024;13(10):2843.
14. Ruijuan Y, Maobin K, Jiajun Q, et al. Assessing the usefulness of a newly proposed metabolic score for visceral fat in predicting future diabetes: results from the NAGALA cohort study. Front Endocrinol. 2023;14:1172323.
15. Vasques AC, Novaes FS, de Oliveira MS, et al. TyG index performs better than HOMA in a Brazilian population: a hyperglycemic clamp validated study. Diabetes Res Clin Pract. 2011;93(3):e98–100.
16. Duan Y, Zhang W, Li Z, et al. Predictive ability of obesity- and lipid-related indicators for metabolic syndrome in relatively healthy Chinese adults. Front Endocrinol. 2022;13:1016581.
17. Li Y, Zheng R, Li S, et al. Association between four anthropometric indexes and metabolic syndrome in US adults. Front Endocrinol. 2022;13:889785.
18. Li Y-W, Kao T-W, Chang P-K, et al. Atherogenic index of plasma as predictors for metabolic syndrome, hypertension and diabetes mellitus in Taiwan citizens: a 9-year longitudinal study. Sci Rep. 2021;11(1):9900.
19. Konstantinova ED, Maslakova TA, Ogorodnikova SY. The predictive capability of several anthropometric indices for identifying the risk of metabolic syndrome and its components among industrial workers. Sci Rep. 2024;14(1):15327.
20. Wei X, Min Y, Song G, et al. Association between triglyceride-glucose related indices with the all-cause and cause-specific mortality among the population with metabolic syndrome. Cardiovasc Diabetol. 2024;23(1):134.
21. Zhao J, Fan H, Wang T, et al. TyG index is positively associated with risk of CHD and coronary atherosclerosis severity among NAFLD patients. Cardiovasc Diabetol. 2022;21(1):123.
22. Li Y, Gui J, Liu H, et al. Predicting metabolic syndrome by obesity- and lipid-related indices in mid-aged and elderly Chinese: a population-based cross-sectional study. Front Endocrinol. 2023;14:1201132.
23. Hu X, Yang Z, Ge W, et al. Evaluating eight indicators for identifying metabolic syndrome in Chinese and American adolescents. Pediatr Res. 2024;96(5):1355–63.
24. Regitz-Zagrosek V, Lehmkuhl E, Weickert MO. Gender differences in the metabolic syndrome and their role for cardiovascular disease. Clin Res Cardiol. 2006;95(3):136–47.
25. 中华医学会糖尿病学分会. 中国2型糖尿病防治指南 (2020年版). 中华糖尿病杂志, 2021, (04): 315-409
26. Gurka MJ, Filipp SL, Musani SK, et al. Use of BMI as the marker of adiposity in a metabolic syndrome severity score: derivation and validation in predicting long-term disease outcomes. Metabolism. 2018;83:68–74.
27. Khoury M, Manlhiot C, McCrindle BW. Role of the waist/height ratio in the cardiometabolic risk assessment of children classified by body mass index. J Am Coll Cardiol. 2013;62(8):742–51.
28. Su S-Y, Lin T-H, Liu Y-H, et al. Sex difference in the associations among obesity-related indices with hyperuricemia in a large Taiwanese population study. Nutrients. 2023;15(15):3419.
29. Amato MC, Giordano C, Galia M, et al. Visceral adiposity index: a reliable indicator of visceral fat function associated with cardiometabolic risk. Diabetes Care. 2010;33(4):920–2.
30. Liu PJ, Lou HP, Zhu YN. Screening for metabolic syndrome using an integrated continuous index consisting of waist circumference and triglyceride: a preliminary cross-sectional study. Diabetes Metab Syndr Obes. 2020;13:2899–907.
31. Xiaozhou S, Chunli Z, Xianwei Z. Association between METS-IR and heart failure: a cross-sectional study. Front Endocrinol. 2024;15:1416462.
32. Zhao Y, He Y, Zhang L, et al. Effect of CVAI on the incidence of MASLD compared to BMI in populations with different body types: a prospective cohort study in China. Nutr Metab Cardiovasc Dis. 2024;34(2):307–16.
33. Zhang Y, Wu X, Liu G, et al. Association between cardiometabolic index and erectile dysfunction among US adults: a cross-sectional analysis of the national health and nutrition examination survey 2001–2004. Int J Impot Res. 2024;36(4):422–9.
34. Fuyan Z, Yiying W, Jie Z, et al. Association between Metabolic Score for Visceral Fat and the risk of hypertension in different ethnic groups: a prospective cohort study in Southwest China. Front Endocrinol. 2024;15:1302387.
35. Fang-Fei Y, Jian G, Yi-Ning G, et al. Association between atherogenic index of plasma and all-cause mortality and specific-mortality: a nationwide population-based cohort study. Cardiovasc Diabetol. 2024;23(1):276.
36. Cho HW, Chung W, Moon S, et al. Effect of sarcopenia and body shape on cardiovascular disease according to obesity phenotypes. Diabetes Metab J. 2021;45(2):209–18.
37. Darroudi S, Soflaee SS, Hosseini ZS, et al. The visceral adiposity index and lipid accumulation product as predictors of cardiovascular events in normal weight subjects. Clin Nutr ESPEN. 2022;52:190–7.
38. Martins CA, do Prado CB, Santos Ferreira JR, et al. Conicity index as an indicator of abdominal obesity in individuals with chronic kidney disease on hemodialysis. PLoS ONE. 2023;18(4): e0284059.

39. Miao H, Zhou Z, Yang S, Zhang Y. The association of triglyceride-glucose index and related parameters with hypertension and cardiovascular risk: a cross-sectional study. Hypertens Res. 2024;47(4):877–86.
40. Craig CL, Marshall AL, Sjöström M, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35(8):1381–95.
41. 健康中国行动(2019—2030年). 2019.
42. Miranda PJ, DeFronzo RA, Califf RM, Guyton JR. Metabolic syndrome: definition, pathophysiology, and mechanisms. Am Heart J. 2005;149(1):33–45.
43. Stančáková A, Laakso M. Genetics of metabolic syndrome. Rev Endocr Metab Disord. 2014;15(4):243–52.
44. Xie J, Li Y, Zhang Y, et al. Sleep duration and metabolic syndrome: an updated systematic review and meta-analysis. Sleep Med Rev. 2021;59:101451.
45. Hiramatsu Y, Ide H, Furui Y. Differences in the components of metabolic syndrome by age and sex: a cross-sectional and longitudinal analysis of a cohort of middle-aged and older Japanese adults. BMC Geriatr. 2023;23(1):438.
46. Crichton G, Bryan J, Buckley J, Murphy K. Dairy consumption and metabolic syndrome: a systematic review of findings and methodological issues. Obes Rev. 2011;12(5):e190-201.
47. Guo Q, Zhao Y, Zhao J, et al. Physical activity attenuated the associations between ambient air pollutants and metabolic syndrome (MetS): a nationwide study across 28 provinces. Environ Pollut. 2022;315:120348.
48. Gallardo-Alfaro L, Bibiloni MDM, Mascaró CM, et al. Leisure-time physical activity, sedentary behaviour and diet quality are associated with metabolic syndrome severity: the PREDIMED-plus study. Nutrients. 2020;12(4):1013.
49. Chenyu Z, Sisi F, Haoyu W, et al. Factors related to metabolic syndrome development and recovery in Chinese adults: a prospective longitudinal study. Front Endocrinol. 2022. https://doi.org/10.3389/fendo.2022.923650.
50. Omar Yaxmehen B-C, Neftali Eduardo A-V, Arsenio V-V, et al. Metabolic score for visceral fat (METS-VF), a novel estimator of intra-abdominal fat content and cardio-metabolic health. Clin Nutr. 2019;39(5):1613.
51. Feng L, Chen T, Wang X, et al. Metabolism score for visceral fat (METS-VF): a new predictive surrogate for CKD risk. Diabetes Metab Syndr Obes. 2022;15:2249–58.
52. López-González AA, Jover AM, Martínez CS, et al. The CUN-BAE, deurenberg fat mass, and visceral adiposity index as confident anthropometric indices for early detection of metabolic syndrome components in adults. Sci Rep. 2022;12(1):15486.
53. Zheng S, Shi S, Ren X, et al. Triglyceride glucose-waist circumference, a novel and effective predictor of diabetes in first-degree relatives of type 2 diabetes patients: cross-sectional and prospective cohort study. J Transl Med. 2016;14(1):1–10.
54. Keke D, Xuanyang W, Jinxia H, et al. The association between triglyceride-glucose index and its combination with obesity indicators and cardiovascular disease: NHANES 2003–2018. Cardiovasc Diabetol. 2024;23(1):8.

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