Comparison of obesity indices and triglyceride glucose related parameters to predict type 2 diabetes mellitus among normal-weight elderly in China

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Research Article

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Abstract

Purpose: Although a significant proportion of type 2 diabetes mellitus (T2DM) cases arose from normal-weight individuals, studies on indicators that can predict T2DM in normal-weight people are limited. Accordingly, this study aims to investigate the predictive value of obesity indices and triglyceride glucose related parameters (TyG-related parameters) in T2DM among normal-weight Chinese elderly.

Methods: A total of 24,215 normal-weight Chinese elderly (age ≥ 60 years) [body mass index--BMI (18.5-23.9 kg/m^2)] were included. Obesity indices and triglyceride glucose related parameters (TyG-related parameters) included waist circumference (WC), waist-to-height ratio (WHtR), visceral adiposity index (VAI), lipid accumulation product (LAP), and TyG-related parameters (TyG, TyG-BMI, TyG-WC, and TyG-WHtR). Multivariate logistic regression analysis was performed to examine the associations between obesity-and TyG-related indices and T2DM. The areas under the curve (AUC) of the receiver-operating characteristic (ROC) curve analyses were used to evaluate and compare the predictive value of the different indices.

Results: The prevalence of T2DM was 14.2% in normal-weight individuals. Among the indices, TyG was significantly associated with T2DM among men and women, respectively (adjusted odds ratio--aOR 19.005; 95% CI 13.235–27.291) and (aOR 25.262; 95% CI 16.957–37.634). Compared with other indices, TyG had the highest AUC value for T2DM in men (AUC: 0.818, 95% CI 0.810–0.825) and women (AUC: 0.824, 95% CI 0.814–0.833).

Conclusions: TyG is an effective marker and outperforms than other indices when predicting T2DM in the normal-weight Chinese elderly population.

Level of evidence: Level V

Introduction

Obesity is a well-established risk factor for type 2 diabetes mellitus (T2DM) [1, 2]. Body Mass Index (BMI) is frequently used as a measure of obesity[3, 4]. However, the T2DM may not be presented in all obese individuals[5-7]. Previous studies have revealed that the prevalence of T2DM in normal-weight individuals (BMI: 18.5–25kg/m^2) ranged from 15 to 30% [8-10]. Many studies focused on the prediction of risk factors for T2DM in overweight and obese people[11], but indicators that identifying patients with T2DM in normal-weight individuals are limited. Further, normal-weight individuals may not monitor their health indices[12]. Thus, identifying an effective marker in predicting T2DM among normal-weight individuals is necessary.

Beside of BMI, several surrogate parameters have recently been proved to be potential indicators for identifying insulin resistance (IR), T2DM and cardiovascular metabolic diseases[13-17]. For example, waist circumference (WC) and waist-to-height ratio (WHtR) are also widely used for detecting the risk of T2DM [13,14]. Visceral adiposity index (VAI) and lipid accumulation product (LAP) are used as novel markers of visceral fat to predict the metabolic syndrome (MetS), T2DM and arterial stiffness [15,16]. Moreover, the triglyceride glucose related parameters (TyG, TyG-BMI, TyG-WC, TyG-WHtR) have been identified as excellent surrogate markers for T2DM screening [17].

Previous studies have reported that the differences in obesity indices and TyG-related parameters for identifying the predictive ability of T2DM were mainly caused by ethnicity and geographic variation of the population[18, 19]. Nevertheless, no study has assessed the effectiveness of these indices as predictors of T2DM in normal-weight Chinese people. Furthermore, the global guideline for managing older people with T2DM showed that the older age group (60 years or more) is a high-risk factor for T2DM[20]. Hence, choosing appropriate indicators to predict the T2DM in normal-weight Chinese elderly are considered important enough from a public health perspective. In this study, we aimed to investigate the clinical utility of several surrogate markers for predicting T2DM in normal-weight Chinese elderly.

Materials And Methods

Participants

A total of 37,628 adults were recruited from a health screening program undertaken in six hospitals at the Center of Medical Examination from August to December 2019 in Shenzhen (i.e., Baoan Central hospital, Baoan District Traditional Chinese Medicine Hospital, Fuyong People's Hospital, Shajing Hospital, Shiyan Hospital, and Songgang Hospital). Individuals who aged ≥ 60 years and had informed consent were included. Exclusion criteria were used as follows: 1) adults who did not fast for at least 8 hours before the test; 2) corticosteroid was used in the last 6 months; 3) people who refused to participate in this study. Finally, 13,413 individuals were excluded from our study, including subjects with BMI < 18.5 kg/m^2 (5588 individuals) and ≥ 24 kg/m^2 (7825 individuals), and 24,215 subjects were enrolled.

Definitions

The participants were divided into two groups (with T2DM and without T2DM). The normal-weight was defined as BMI: 18.5-23.9 kg/m^2, according to the recommendations of Working Group on Obesity of China (WGOC)[21]. T2DM was defined as: 1) FPG ≥ 7.0 mmol/L[22]; 2) previous diagnosis of T2DM; 3) using antidiabetic medications. Socio-demographic information, risk factors, and relevant medical records of participants were collected in the study. The participants were asked the following questions about lifestyle: 1) smoking: “Have you smoked a cigarette, cigar or pipe of tobacco in the last 30 days?” (Yes/No); 2) drinking: “Have you had an alcoholic drink of any kind in the last 12 months?” (Yes/No); 3) the frequency of physical activity: “Do you exercise regularly a week, low (e.g. walking, Tai Chi) or moderate (e.g. biking, jogging) or high (e.g. playing badminton, swimming)?” The obesity- and TyG-related indices were calculated using the following formula[17, 23-26]:

1) WHtR =WC/Height.

With WC in cm, Height in cm.

2) VAI (Men) = [WC/39.68 + (1.88 × BMI)] × (TG/1.03) × (1.31/HDL-C)

VAI (Women) = [WC/36.58 + (1.89 × BMI)] × (TG/0.81) × (1.52/HDL-C).

With WC in cm, BMI in kg/m^2, TG and HDL-C both in mmol/L

3) LAP (Men) $=$ [WC-65] ×TG.

LAP (Women) $=$ [WC-58] ×TG.

With WC in cm and TG in mmol/L.

4) TyG = Ln [(TG× FPG)/2][26]. With TG and FPG both in mg/dL

5) TyG-BMI = TyG × BMI. TyG-WC = TyG × WC. TyG-WHtR = TyG × WHtR.

Anthropometric and Laboratory Measurement

Body weight (kg) and height (cm) were measured without hats and shoes. The calculation of BMI (kg/m^2) was weight (kg) divided by the square of height (m). WC (cm) was measured using non-elastic tape at the umbilical level at the end of normal expiration. Blood pressure (mmHg) was measured with a standardized mercury sphygmomanometer on the same arm three times after a resting period of at least 5 minutes. The average of the measurements was recorded. Venous blood samples were collected after the participants had fasted for at least 8 hours. Participants were asked to refrain from caffeine, alcohol, smoking, and strenuous activities for 8 hours prior to blood sampling. Plasma levels of the fasting plasma glucose (FPG), triglyceride (TG), total cholesterol (TC), low-density lipid cholesterol (LDL-C) and high-density lipid cholesterol (HDL-C) were analyzed with an automated biochemical analyzer.

Statistical Analysis

Data analyses were performed with IBM SPSS Statistics, version 25 (IBM Corporation, Armonk, NY, USA) and MedCalc Statistical Software version 19.2 (MedCalc Software BVBA, Ostend, Belgium). Categorical variables were expressed in frequency and percentage. The Chi-squared test was used to compare categorical variables between groups. Continuous variables were expressed as mean ± standard deviation (SD) or interquartile ranges, Student's *t*-test or Mann−Whitney *U* test were applied to identify different groups in continuous variables. Given the sexual dimorphism in body composition, multivariate logistic regression analysis and receiver-operating characteristic (ROC) curve analyses were presented stratified by sex. The binary logistic regression analysis was used to estimate the odds ratio (OR) (with the corresponding 95% confident interval–95% CI) of T2DM with the Obesity indices and TyG-related parameters the diagnostic value for T2DM was defined by areas under the curve (AUC) in ROC curve analyses. The cut-off point was selected according to Youden index (sensitivity + specificity -1). Two-tailed tests were used for all significant tests, and *p*-values less than 0.05 were considered statistically significant.

Results

Demographic and Clinical Characteristics of Participants

The characteristics of subjects are shown in **Table 1.** Of the 24,215 participants, 10,661 (44.02%) were men and 13,554 (55.98%) were women. The mean age was 71 years, and the prevalence of T2DM was 14.2%.

Subjects with T2DM showed higher obesity indices and TyG-related parameters than those who without T2DM ($p<0.05$).

Associations of Indicators with T2DM risk

We divided each index into ascending sex-specific quartile values and used multivariate logistic regression analysis to calculate the OR with 95% CI for T2DM across the quartiles. The quartile 1 was used as the reference group, and after adjusting the factors of age, smoking, drinking and physical activity, the results showed the adjusted OR (aOR) for T2DM was increased with elevated quartiles of VAI, LAP and TyG (See **Table 2**). In men, TyG presented the highest aOR for T2DM, reached 19.005 (95 % CI 13.235–27.291) for the top quartile as compared with the bottom quartile, followed by TyG-WHtR (Q4 2.356, 95% CI 1.557–3.566), VAI (Q4 1.933, 95% CI 1.479–2.527), LAP (Q4 1.553, 95% CI 1.099–2.094) and WC (Q4 1.514, 95% CI 1.130–2.029). In women, the aOR and 95% CI for T2DM were highest for TyG at 25.262 (95% CI 16.957–37.634), followed by VAI (Q4 1.954, 95% CI 1.541–2.478), LAP (Q4 1.754, 95% CI 1.337–2.300) and TyG-WC (Q4 1.723, 95% CI 1.164–2.552).

The Predictive value of Each Index for T2DM

The results of the ROC curve analyses for each index were shown in **Table 3** and **Fig.1.** The largest AUC observed in men was TyG (AUC: 0.818, 95% CI 0.810–0.825), followed by TyG-WC (AUC: 0.771, 95% CI 0.763–0.779) and TyG-WHtR (AUC: 0.768, 95% CI 0.760–0.776). The predictive values between the WC (AUC: 0.586, 95% CI 0.570–0.602) and WHtR (AUC: 0.571, 95% CI 0.555–0.587) were similar. In women, the AUC was largest for TyG (AUC: 0.824, 95% CI 0.814–0.833), followed by TyG-WC (AUC: 0.766, 95% CI 0.755–0.777). TyG-BMI and TyG-WHtR showed similar predictive ability (AUC: 0.760) when predicting the prevalence of T2DM in Chinese elderly. In **Table 3**, when predicting T2DM, TyG had the highest sensitivity (76.09 %, 73.87 % man and women, respectively), specificity (72.38 %, 75.90 % men and women, respectively) and Youden index (0.48, 0.50 men and women, respectively) in both sexes. Pairwise comparison of ROC curves of TyG in **Table 4** showed that the AUC of TyG was significantly different from the AUC of other markers in both sexes.

Discussion

In this study, we compared the obesity indices with TyG-related parameters to predict T2DM in Chinese elderly with normal-weight. Our results showed that TyG performed with the highest OR and largest AUC in the whole sample population. Therefore, TyG could be an effective marker to predict T2DM in elderly with normal-weight. In addition, our results suggest an optimal cut-off points of WC and WHtR for T2DM in Chinese elderly with normal-weight were WC ≥ 84.3 cm and WHtR ≥ 0.49 for men, and WC ≥ 79.8 cm and WHtR ≥ 0.52 for women.

The cut-off points of BMI were defined by the World Health Organization (WHO). BMI of 18.5–23 kg/m^2 was defined as normal-weight for Asians. Nevertheless, compared with Caucasian, Asians have the higher risk of T2DM even the BMI is less than 23.0 kg/m^2 [27]. Weight gain may lead to IR and significantly increase the risk of diabetes in East Asians. Due to the differences in culture and lifestyle, the risk of T2DM is higher among normal-weight (BMI: 18.5–23.9 kg/m^2) population in China than many other countries[9]. Further, T2DM is concealed and easily miss-diagnosed in elderly people. Thus, efficacious indicators that can predict T2DM in normal-weight Chinese elderly are urgently needed.

Previous studies have found that even people with the same WC, shorter individuals may have a higher risk for metabolic than taller individuals[28]. A meta-analysis reported that WHtR was a superior tool for predicting diabetes[29], dyslipidemia, hypertension, and cardiovascular disease (CVD), compared with BMI and WC. However, our study revealed that WHtR was not significant associated with T2DM among the normal-weight elder population. The explanations for these issues remain to be elucidated, and may be related to the sample population is normal-weight people. The AUC values were determined by ROC curves, which showed that WC and WHtR had poorer diagnostic accuracy than LAP, VAI, and TyG-related indices. This finding suggested that the inclusion of biochemical predictors increased the diagnostic power of T2DM, as opposed to use anthropometric parameters only. The thresholds for WC and WHtR in predicting the risk of T2DM among Chinese adults are still controversial. Currently, the recommended thresholds for overweight and central obesity in China are WC ≥ 85cm and 90cm for men, and WC ≥ 80cm and 85cm for women[21]. Our data observed cut-off value of WC for normal-weight people was lower than recommendations. The result suggested that an initial measurement of WC was necessary to prevent T2DM in elderly with normal-weight. Intriguingly, we found that WHtR was more sensitive (70.80 %) than WC (50.22 %) in men, despite WHtR had the lowest AUC (0.571 for men). As a consequence, WHtR may have a better predictive ability than WC, and can be used for T2DM screening. According to previous reports, WHtR ≥ 0.5 might be the best cut-point value for diagnosing T2DM[30]. A study by Yang et al[31]. reported the WHtR cut-offs for the T2DM detection were 0.512 and 0.514 for men and women among 996 older adults in China. In our study, the cut-off point of WHtR was 0.49 and 0.52 for men and women, which suggested that the cut-off value in elderly Chinese men with normal-weight had decreased. However, the results of the WC and WHtR cut-off values need to be interpreted with caution, as the sample data for our study was collected only from Shenzhen -- a large southern city in China.

As a clinical marker of abdominal fat function, VAI was used to predict the risk of cardiometabolic in healthy individuals[32]. Our study showed that the quartile 4 of VAI was 1.933 (95% CI 1.479–2.527) in men, and 1.954 (95% CI 1.541–2.478) in women, comparing with the quartiles 1 of VAI. A study reported that Chinese VAI (CVAI) had a significant advantage over BMI and WC measurements in T2DM detection[33]. By contrast, Mohammadreza B et al.[34] have indicated that compared to BMI and WC, VAI was not a suitable index to predict T2DM. In our study, VAI was not an appropriate surrogate marker for identifying normal-weight T2DM (AUC: 0.620, 0.625, sensitivity: 48.55% and 60.29% for men and women, respectively), the indicator had a relatively lower discriminatory ability compared with TyG-related parameters. LAP is considered to be a better predictor of T2DM, compared with anthropometric indicators. Several studies claimed that LAP had ideal predictive value for T2DM patients in German[15], Japanese[35] and Iranians[36]. However, a cohort study indicated that a high LAP index was associated with a higher diagnostic risk of T2DM in Indonesian women, but it did not predict the development of T2DM[37]. We found that LAP and VAI had similar low AUC values, which means that these indicators may not be effective surrogate markers for identifying T2DM in normal-weight elderly in China.

A national prospective cohort study has shown that IR was strongly associated with diabetes events than dose β-cell dysfunction in Chinese adults[38]. Therefore, IR is a vital indicator for predicting the development of T2DM in Chinese people. Recently, TyG-related parameters include TyG, TyG-BMI, TyG-WC and TyG-WHtR have become alternative indices for IR due to their convenience and universal availability[17]. S-H Lee et al. found that TyG was a helpful indicator to identify individuals at higher risk of metabolic diseases among normal-weight subjects[39]. Zhang et al. indicated that a high baseline TyG was associated with the development of T2DM, regardless of obesity status[40]. Although few studies have examined the relationship between TyG and T2DM in normal-weight individuals, the results from S-H Lee et al.[39] and Zhang et al.[40] were similar to ours. Indeed, our study found that TyG was more effective than other markers. The mechanism of TyG in T2DM is not clear, and several studies have provided clues to unpack the underlying mechanisms. First, previous studies demonstrated that TyG might have strong predictive ability for IR[41, 42]. TyG has better predictive performance of IR than homeostatic model assessment (HOMA) in the Brazilian population[43]. Second, TyG is a composite index of fasting TG and FPG. Glycerol and fatty acids are the products of TG lipolysis, and hepatic gluconeogenesis is promoted by the two metabolites[44, 45]. Increased TG in islets can interfere with glucose metabolism, resulting in β-cell dysfunction and IR[46]. Third, TyG may reveal the dual dimensions of IR. FPG primarily reflects liver IR, while fasting TG mainly reflects fat cell IR[47, 48]. Since the main pathophysiological basis of T2DM is IR[38], this may explain the high predictive power of TyG in people with T2DM. Given the limited data at the HOMA-IR level, the interpretation of this mechanism should be careful, and further studies are needed. We found that T2DM risk reached the highest level in quartile 4 of TyG for men (aOR 19.005, 95% CI 13.235–27.291) and women (aOR 25.262, 95% CI 16.957–37.634), respectively. Our study shows that all TyG-related parameters has the ability to identify individuals with T2DM (AUC>0.5). TyG had the highest AUC value (0.818, 0.824 men and women, respectively) and Youden index (0.48, 0.50, men and women, respectively), suggesting that TyG was strongest associated with T2DM risk in normal-weight Chinese elderly compared with other markers. Moreover, the AUC of TyG differs significantly from the AUC of other markers, meaning that TyG may have clinical significance in identifying T2DM.

Different studies showed differences in the cut point of TyG in diagnosing T2DM. In a cohort study of European whites, subjects with a TyG level of 8.31 or higher had an increased risk of T2DM[49]. Lee JW et al.[50] showed that the optimal cut-off value for TyG was 8.52 in people with T2DM. Our study shows that the best cut-off values for TyG are 7.17 and 7.40 for men and women, respectively. TG concentrations are known to vary among ethnic groups, so additional studies are needed to assess TyG in other populations. Unlike our study, TyG did not increase the predictive power of T2DM in Iranians[19]. TyG-BMI and TyG-WC were significantly better than TyG in predicting T2DM risk in Korean population[51]. TyG-WC was the best marker for identifying the risk of prediabetes and T2DM in a study (59 age years with overweight adults) from Shanghai, China[52]. Thus, additional studies on TyG-related parameters and T2DM among different age groups and ethnicities need to be validated.

Strength and limits

Some strengths and limitations require careful consideration in interpreting the results of this study. The strengths as follows. First, it was based on a large elderly population in the Chinese community and has no report previously compared the predictive ability of obesity indices and TyG-related parameters in T2DM among elderly people with normal-weight. Second, FPG and TG played a key role in the development of T2DM in elderly people with normal-weight. Third, we found that TyG was the best indicator for predicting T2DM. TyG can help to identify T2DM individuals who could be considered as being not at high-risk group (normal-weight individuals). Forth, we found the optimal cut-off point between WC and WHtR in relationship with T2DM, which may help to improve the clinical practice on the detection of the risk of T2DM in the elderly people with normal-weight. These findings have important implications for the primary prevention of T2DM in elderly population. There are some limitations in this study. First, the sample population only came from Shenzhen, which might not represent the characteristics of all the Chinese elderly people. Second, there was no data on the 2h post-challenge plasma glucose or measurement of HbA1c levels to diagnose T2DM, which might lead to the underdiagnosis of T2DM in study subjects. Third, the generalizability of our results to other ethnic groups may be limited due to some selective biases.

What is already known on this subject?

Overweight and obesity are well-known risk factors for T2DM. However, some populations (particularly among normal-weight Chinese people) are at higher risk of T2DM, despite having a lower body mass index (BMI) than other ethnic groups. Some obesity and TyG related parameters (BMI, WC, WHtR, LAP, VAI, TyG, TyG-BMI) are used to predict IR, MetS, CVD. Nevertheless, no previous study has assessed the effectiveness of these indices as predictors of T2DM in the Chinese elderly population with normal-weight.

What this study adds?

TyG had significantly and strongest association with normal-weight T2DM elderly in China. The best cut-off point of WC and WHtR for T2DM in Chinese elderly with normal-weight (men were WC $\geq$ 84.3 cm and WHtR $\geq$ 0.49, women were WC $\geq$ 79.8 cm and WHtR $\geq$ 0.52) when screening the T2DM in the normal weight elder population.

Conclusion

Compared with other indices, TyG was the best marker for predicting T2DM in normal-weight elderly people in China. We propose to use TyG as a supplementary indicator to predict T2DM in health check-up and clinical practice in the elderly population. Considering the differences of obesity indices and TyG-related parameters in predicting the risk of T2DM in different populations, further studies were warranted to identify their associations with the risk of T2DM.

Declarations

Author contribution

Z.X.L and H.J conceived the study. M.Z.X, J.F., H.B.X., Y.G., C.W., Z.Y.D., X.L., responsible for data collection, sorting out data, and played a role in the writing of the manuscript. K.P. and X.W wrote the manuscript. W.N.F., Q.F.T., Y.H., L.R.Z. gave advice on methodology and contributed to reviewing or revising the study. All authors read and approved the final manuscript. Z.X.L. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Ethical approvel

The study was approved by the Ethics Committee of all the six hospitals. This article does not contain any studies with animals performed by any of the authors.

Informed consent

Informed consent was obtained from each participant enrolled in the study

Declarations

The authors declare no conflict of interest in this study.

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Tables

Table 1. Demographic and clinical characteristics of the participants

Variables	Without T2DM(*n*=20,795)	T2DM(*n*=3420)	Total(*n*=24,215)	*p*-value
	Median±SD or *n* (%)	Median±SD or *n* (%)	Median±SD or *n* (%)	
Sex				<0.001
Men	9281(38.33)	1380(5.70)	10,661(44.03)	
Women	11,514(47.55)	2040(8.42)	13,554(55.97)	
Mean age (years)	70.95±5.71	71.47±5.70	71.03±5.71	<0.001
Age category				<0.001
60-69 yrs	10,775(44.50)	1596(6.59)	12,371（51.09）	
70-79 yrs	8021(33.12)	1459(6.03)	9480（39.15）	
80 yrs+	1999(8.25)	365(1.51)	2364（9.76）	
BMI (kg/m^2)	21.75±1.44	21.96±1.40	21.78±1.44	<0.001
SBP (mm Hg)	132.87±18.57	136.49±19.05	133.38±18.68	<0.001
DBP (mm Hg)	76.67±10.73	77.11±10.57	76.73±10.70	<0.001
TC (mmol/L)	5.13±1.11	5.20±1.22	5.14±1.13	<0.001
TG (mmol/L)	1.45±0.97	1.87±1.36	1.51±1.04	<0.001
HDL-C (mmol/L)	1.45±0.44	1.37±0.40	1.43±0.43	<0.001
LDL-C (mmol/L)	3.01±0.95	3.05±1.01	3.02±0.96	<0.001
FPG (mmol/L)	5.41±0.67	9.28±2.69	5.96±1.80	<0.001
Obesity indices				
WC (cm)	81.26±6.27	82.73±6.16	81.47±6.27	<0.001
WHtR	0.51±0.04	0.52±0.04	0.51±0.041	<0.001
VAI	1.91±3.01	2.65±2.64	2.02±2.97	<0.001

LAP	30.27±25.21	41.92±34.74	31.91±27.08	<0.001
TyG-related parameters				
TyG	7.00±0.53	7.74±0.63	7.10±0.60	<0.001
TyG-BMI	152.43±16.53	169.94±18.38	154.90±17.87	<0.001
TyG-WC	569.38±65.76	640.19±73.04	579.38±71.24	<0.001
TyG-WHtR	3.59±0.43	4.04±0.48	3.66±0.46	<0.001
Lifestyle				
Current smoking	3063(12.65)	357(1.47)	3420(14.12)	0.078
Current drinking	2962(12.23)	458(1.89)	3420(14.12)	<0.001
Frequency of physical activity				0.222
Low	13,094(54.07)	2140(8.84)	15,234(62.91)	
Moderate	2993(12.36)	529(2.18)	3522(14.54)	
High	4708(19.44)	751(3.10)	5459(22.55)	

Data are presented as means ± standard deviation, and interquartile range or frequencies. *p* values are from *t*-tests or Chi-square tests for analysis of variance for continuous variables and categorical variables. Abbreviations: T2DM,Type 2 Diabetes Mellitus; BMI , Body Mass Index; SBP, Systolic Blood Pressure, DBP, Diastolic Blood Pressure; TC, Total Cholesterol; TG, Triglyceride; HDL-C, high-density lipid cholesterol; LDL-C, low-density lipid cholesterol; FPG, fasting plasma glucose; WC, Waist Circumference; WHtR, Waist Height-Ratio; VAI , Visceral Adiposity Index; LAP, Lipid Accumulation Product; TyG, Triglyceride Glucose; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR;

Table 2. aOR for T2DM in quartiles of each index

Categories	WC	WHtR	VAI	LAP
Men				
Q1	Ref.	Ref.	Ref.	Ref.
Q2	1.216(0.974,1.518)	0.991(0.819,1.201)	1.163(0.947,1.429)	1.224(0.972,1.542)
Q3	1.239(0.946,1.624)	0.876(0.965,1.103)	1.373(1.090,1.729)	1.227(0.927,1.624)
Q4	1.514(1.130,2.029)	1.095(0.842,1.425)	1.933(1.479,2.527)	1.553(1.099,2.094)
Women				
Q1	Ref.	Ref.	Ref.	Ref.
Q2	1.123(0.955,1.320)	0.879(0.732,1.056)	1.155(0.965,1.382)	1.315(1.088,1.589)
Q3	1.085(0.890,1.323)	0.952(0.781,1.159)	1.567(1.278,1.920)	1.428(1.136,1.793)
Q4	1.133(0.908,1.414)	0.989(0.789,1.240)	1.954(1.541,2.478)	1.754(1.337,2.300)
Categories	TyG	TyG-BMI	TyG-WC	TyG-WHtR
Men				
Q1	Ref.	Ref.	Ref.	Ref.
Q2	3.136(2.226,4.339)	0.966(0.735,1.270)	1.122(0.785,1.604)	1.593(1.166,2.177)
Q3	6.819(4.867,9.545)	0.783(0.585,1.048)	0.976(0.641,1.487)	1.572(1.080,2.089)
Q4	19.005(13.235,27.291)	0.968(0.705,1.329)	1.122(0.705,1.786)	2.356(1.557,3.566)
Women				
Q1	Ref.	Ref.	Ref.	Ref.
Q2	3.347(2.268,4.938)	0.809(0.628,1.041)	1.115(0.811,1.533)	1.075(0.745,1.550)
Q3	7.568(5.128,11.167)	0.775(0.601,1.000)	1.239(0.861,1.782)	1.247(0.822,1.892)
Q4	25.262(16.957,37.634)	1.024(0.785,1.335)	1.723(1.164,2.552)	1.264(0.809,1.974)

Adjusting the factors of age, smoking, drinking and physical activity.

Abbreviations: aOR, adjusted Odds Ratio; Q, Quartile; Ref, Reference; WC, Waist Circumference; WHtR, Waist Height-Ratio; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; TyG, Triglyceride Glucose; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR;

Table 3. ROC curve analyses for each index in predicting T2DM

Parameters	WC	WHtR	VAI	LAP
Man				
AUC (95% CI)	0.586(0.570,0.602)	0.571(0.555,0.587)	0.620(0.604,0.636)	0.622(0.606,0.638)
p-value	<0.001	<0.001	<0.001	<0.001
Cut-off	≥84.3	≥0.49	≥1.50	≥25.08
Sens. (%)	50.22	70.80	48.55	51.52
Spec. (%)	62.57	39.19	69.67	66.53
Youden index	0.13	0.10	0.18	0.18
Women				
AUC (95% CI)	0.565(0.552,0.578)	0.556(0.543,0.570)	0.625(0.612,0.638)	0.630(0.617,0.643)
p-value	<0.001	<0.001	<0.001	<0.001
Cut-off	≥79.8	≥0.52	≥2.04	≥33.61
Sens. (%)	67.16	65.03	60.29	58.38
Spec. (%)	42.70	42.97	59.26	60.80
Youden index	0.10	0.09	0.19	0.19
Man	TyG	TyG-BMI	TyG-WC	TyG-WHtR
AUC (95% CI)	0.818(0.810,0.825)	0.760(0.752,0.768)	0.771(0.763,0.779)	0.768(0.760,0.776)
p-value	<0.001	<0.001	<0.001	<0.001
Cut-off	≥7.17	≥163.04	≥608.91	≥3.64
Sens. (%)	76.09	62.54	66.67	70.58
Spec. (%)	72.38	77.35	73.84	69.20
Youden index	0.48	0.40	0.41	0.40
Women				
AUC (95% CI)	0.824(0.814,0.833)	0.760(0.748,0.771)	0.766(0.755,0.777)	0.760(0.749,0.771)
p-value	<0.001	<0.001	<0.001	<0.001
Cut-off	≥7.40	≥162.68	≥592.40	≥3.88
Sens. (%)	73.87	68.24	73.13	70.98
Spec. (%)	75.90	70.84	66.16	68.36
Youden index	0.50	0.39	0.40	0.39

Abbreviations: ROC, Receiver Operating Characteristic Curve; AUC, Area Under Curve; 95% CI, 95% Confidence Interval; Sens, Sensitivity; Spec, Specificity; WC, Waist Circumference; WHtR, Waist Height-Ratio; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; TyG, Triglyceride Glucose; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR;

Table 4. Pairwise comparison of AUC of TyG

Index	Differences between AUC	95% CI	*p*-value
Men			
WC	0.232	(0.213,0.250)	<0.001
WHtR	0.246	(0.268,0.265)	<0.001
VAI	0.198	(0.188,0.207)	<0.001
LAP	0.195	(0.185,0.260)	<0.001
TyG-BMI	0.056	(0.048,0.066)	<0.001
TyG-WC	0.046	(0.036,0.055)	<0.001
TyG-WHtR	0.050	(0.040,0.059)	<0.001
Women			
WC	0.259	(0.243,0.274)	<0.001
WHtR	0.268	(0.252,0.284)	<0.001
VAI	0.199	(0.191,0.206)	<0.001
LAP	0.194	(0.186,0.202)	<0.001
TyG-BMI	0.064	(0.056,0.072)	<0.001
TyG-WC	0.058	(0.050,0.066)	<0.001
TyG-WHtR	0.064	(0.055,0.073)	<0.001

Abbreviations: AUC, Area Under Curve; 95% CI, 95% Confidence Interval; WC, Waist Circumference; WHtR, Waist Height-Ratio; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; TyG, Triglyceride Glucose; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR;

Figures

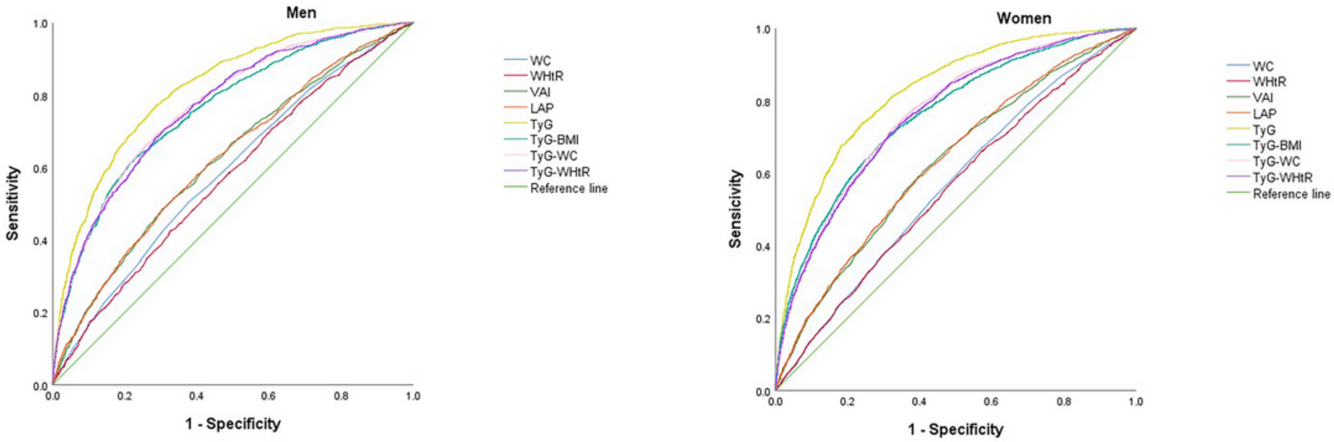

Figure 1

ROC curves for each indices as predictors of T2DM in men and women. A) Man and B) Women. Abbreviations: WC, Waist Circumference; WHtR, Waist Height-Ratio; VAI, Visceral Adiposity Index; LAP, Lipid Accumulation Product; TyG, Triglyceride Glucose; TyG-BMI, TyG related to BMI; TyG-WC, TyG related to WC; TyG-WHtR, TyG related to WHtR;