Triglyceride glucose-waist circumference to height ratio predicts 10-year diabetes risk: the REACTION research

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Research Article

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Abstract

Objective: The aim of this research was to examine the causative association between TyG-WHtR and newly diagnosed diabetes.

Patients and measurements: We organized a retrospective 10-year cohort study of 10150 Chinese adults. After screening out people who were not qualified, the TyG-WHtR level of 7130 participants was calculated in this study. The Jonckheere-Terpstra test was performed to examine an increasing or decreasing trend across TyG-WHtR quartiles. Multivariate Cox regression models were used to investigate the possibility that it has a connection with diabetes.

Results: Within 10 years, 355 participates (4.98%) had new-onset diabetes. The TyG-WHtR index and newly diagnosed diabetes mellitus had a linear correlation, according to Cox regression analysis (HR = 2.798, 95% CI: 2.285 to 3.426, P < 0.001). In terms of sensitivity and specificity, the TyG-WHtR was found to be 73.52% and 62.60% accurate, respectively, with a 95% CI of 0.703–0.756. Additionally, TyG-WHtR-associated diabetes was substantially more prevalent in men, people aged 41 to 50, with a BMI below 18.5 kg/m^2 and no hypertensive condition (P < 0.05).

Conclusions : TyG-WHtR might be an accurate indicator of future diabetes risk.

Introduction

Patients with diabetes, one of the most frequent and prevalent chronic illnesses, suffer from a reduced quality of life and a shorter life expectancy[1,2]. The latest report from the International Diabetes Federation reveals that more than 536 million people aged 20 to 79 will have diabetes by 2021, and that number is expected to rise to 783.2 million by 2045[3]. Type 2 diabetes (T2DM) affects more than 90% of diabetic patients[3-5]. T2DM and its complications are a major cause of disability, functional impairment and premature death and therefore have enormous social and economic costs[6-8]. As a result, it is critical to improve predictions of diabetes onset[9,10].

It is worth noting that a key pathogenic hallmark of T2DM in its early stages is insulin resistance (IR)[11]. IR is a significant underlying abnormality that contributes to diabetes[12,13]. Numerous indices derived from triglyceride glucose (TyG) and anthropometric measurements have been presented in recent years, such as TyG-body mass index (TyG-BMI), TyG-waist circumference (TyG-WC), and TyG-waist to height ratio (TyG-WHtR)[14,15]. Ln[fasting triglycerides (mg/dL) × fasting blood glucose (mg/dL)/2]×WC(cm)/Height(cm) is the formula for TyG-WHtR, which has been posited as a straightforward, low-cost, and convincing surrogate marker for IR and T2DM[15,16]. Numerous studies have established a connection between the TyG-WHtR index and IR, T2DM, nonalcoholic fatty liver disease, metabolic syndrome, and hyperuricemia[15-19]. For this reason, we compared the TyG-WHtR index with follow-up data from the earlier REACTION study, to determine whether there was a strongly link between the occurrence of diabetes and this index.

Materials And Methods

Study subjects

This study was derived from the national multicenter REACTION study initiated by Ruijin Hospital, Shanghai Jiaotong University School of Medicine[20-22]. The study sample was obtained from Luzhou City, Sichuan Province, and was collected by the Affiliated Medicine of Southwest Medical University (a public tertiary care hospital). The initial recruitment was conducted from May to December 2011, and a total of 10,150 participants (all over 40 years of age) were recruited. According to the ADA diagnostic criteria for diabetes, diabetes is diagnosed at an A1C of greater than or equal to 6.5%, fasting blood sugar of greater than or equal to 126 mg/dl and 2-hour blood sugar of greater than or equal to 200 mg/dl[23,24]. Participants with underlying diabetes were excluded. In addition, participants who lacked clinical data to calculate baseline TyG-WHtR values or who lacked 10-year follow-up data were excluded. Ultimately, 8279 participants were enrolled in the study.

Baseline assessments (2011)

As part of the REACTION study's baseline examination, all of the study's information and data were collected using standard questionnaires and calibrated devices by trained personnel (e.g., cardiologists, general practitioners, dietitians, and nurses). Each volunteer completed a medical history form as well as basic demographic data (such as age, gender, and level of education; smoking and drinking habits, medications used, and family medical history). Smokers were divided into three categories based on their history of smoking: none, occasional, and daily smoke[21]. In addition, participants were classified as having no, occasional, or weekly drinking depending on the type, frequency and average quantity of their alcohol consumed[21,22]. Anthropometric indices such as BMI and WHtR were derived by using standard measurements of weight (kg), height (cm), WC (cm), and hip circumference (cm). After resting for at least 30 minutes in a quiet environment during a physical examination, the patient's mean arterial blood pressure was calculated by averaging the readings received from their right arm three times in a row. Hypertension was defined as taking any antihypertensive medication currently or having a systolic blood pressure (SBP) ≥140 mmHg and a diastolic blood pressure (DBP) ≥90 mmHg.

Follow-up for diabetes mellitus

The research population was followed for 10 years from May 2011 through June 2022. The new onset of diabetes mellitus was the outcome event. The Luzhou Health and Wellness Commission and the Luzhou Disease Control Center checked all of the study subjects' follow-up information and chronic disease reporting information.

TyG-WHtR assessment

TyG-WHtR was determined as follows for each individual examined at the initial stage: ln[fasting triglycerides × fasting glucose/2]×WC/height[15]. The serum concentrations of TG and FBG are both expressed in mg/dL, while WC and height are both expressed in cm. For the same sample, TyG-WHtR quartiles at baseline were also calculated for the following purposes: Q1 (<4.01) (n=1783); Q2 (4.01 - 4.46) (n=1782); Q3 (4.47 - 4.94) (n=1783); and Q4 (>4.94) (n=1782).

Assessment of the sample size of the study

In this 10-year retrospective cohort study, we collected detailed interview information directly from 10,150 participants from 2011-2021. However, 1798 individuals with diabetes at baseline and 1222 with missing follow-up data were omitted from the analysis, resulting in a sample size of 7130 participants.

Statistical analysis

Baseline clinical characteristics were compared for target participants using standard descriptive statistics across the baseline TyG-WHtR quartiles. If the variables were regularly distributed, the Kruskal–Wallis test was applied. One-way analysis of variance (ANOVA) was performed to assess differences in normally distributed variables, and the Mann-Whitney test was performed to assess differences in nonnormally distributed variables. The Jonckheere-Terpstra test was performed to examine an increasing or decreasing trend across TyG-WHtR quartiles. Cox regression models were used to analyze the risk of developing diabetes. The risk of acquiring diabetes was correlated with the TyG-WHtR quartiles using Kaplan–Meier curves and the log-rank test. We explored the TyG-WHtR index's anticipated accuracy using receiver operating characteristic (ROC) curves. SPSS was used to perform all statistical analyses (version 26.0).

Results

10-year T2DM incidence

From 2011 to 2021, this study recruited 7130 people, including 2298 men and 4832 women. A total of 350 people were diagnosed with diabetes during this period, and the prevalence of diabetes was 4.98%.

Quartiles of the TyG-WHtR index among the study participants

According to the TyG-WHtR quartiles, participants' baseline clinical and biochemical features are presented in Table 1. Through data analysis, we discovered that with higher quartiles of TyG-WHtR ratio, these patients tended to be accompanied by higher levels of age, BMI, WC, hip circumference, WHtR, SBP, DBP, TC, TG, LDL-c, FPG, HbA1c, ALT, AST, TyG and a higher prevalence of diabetes, hypertension, and coronary heart disease. Conversely, they had a lower level of HDL-c and a lower probability of abstaining from alcohol. However, no powerful correlations were found between TyG-WHtR index quartiles and smoking habits, tea or coffee consumption. In addition, the Jonckheere-Terpstra test showed that HDL-c levels decreased as the TyG-WHtR index increased, $z = -20.101$, $p < 0.001$, while the remaining continuous variables increased as the TyG-WHtR index increased.

Table 1 Characteristics according to TyG-WHtR quartile

Baseline characteristics	TyG-WHtR Quartile 1 (n=1783)	Quartile 2 (n=1782)	Quartile 3 (n=1783)	Quartile 4 (n=1782)	P value	Z, P_{trend}
Diabetes 10-year incidence, n (%)	27(1.5%)	43(2.4%)	87(4.9%)	198(11.1%)	<0.001†	-
age	53.86± 9.67	56.85±10.15	58.50±9.67	60.57±9.79	<0.001*†	21.118, <0.001*†
Male sex, n (%)	582(32.6%)	598(33.6%)	592(33.2%)	526(29.5%)	<0.039*	-
BMI, kg/m^2	20.76±2.33	22.75±2.20	24.38±2.41	26.60±3.25	<0.001*†	61.403, <0.001*†
WC, cm	71.67±5.60	79.30±4.87	85.04±5.38	91.88±6.88	<0.001*†	75.437, <0.001*†
Hipline, cm	87.15±6.78	91.95±5.77	95.36±5.85	99.60±6.89	<0.001*†	53.393, <0.001*†
WHtR	0.45±0.03	0.50±0.02	0.54±0.03	0.59±0.04	<0.001*†	83.796, <0.001*†
SBP, mmHg	113.75±16.90	121.19±18.27	126.08±19.39	131.34±18.79	<0.001*†	29.993, <0.001*†
DBP, mmHg	71.80±9.45	75.49±10.48	77.71±11.18	79.55±10.45	<0.001*†	22.985, <0.001*†
TC, mmol/L	4.16±1.05	4.50±1.08	4.66±1.08	4.91±1.14	<0.001*†	19.926, <0.001*†
TG, mmol/L	0.87±0.33	1.20±0.49	1.50±0.74	2.51±1.92	<0.001*†	57.197, <0.001*†
HDL-c, mmol/L	1.38±0.38	1.30±0.35	1.25±0.32	1.15±0.30	<0.001*†	-20.101 <0.001*†
LDL-c, mmol/L	2.25±0.73	2.57±0.79	2.68±0.81	2.72±0.81	<0.001*†	17.549, <0.001*†
FPG, mmol/L	5.18±0.44	5.31±0.44	5.42±0.49	5.58±0.50	<0.001*†	25.349, <0.001*†
HbA1c, %	5.68±0.39	5.74±0.38	5.79±0.38	5.86±0.37	<0.001*†	14.968, <0.001*†
ALT, mmol/L	11.42±9.16	13.35±9.13	14.65±10.53	18.24±13.25	<0.001*†	25.634, <0.001*†
AST, mmol/L	19.49±10.61	20.52±9.89	21.25±10.85	23.61±14.85		15.747,

					<0.001*†	<0.001*†
TyG	8.12±0.36	8.45±0.38	8.69±0.40	9.14±0.56	<0.001*†	59.582, <0.001*†
Family history of diabetes, n (%)	355(19.9%)	302(16.9%)	307(17.2%)	291(16.3%)	<0.026*	-
Hypertension	105(5.9%)	194(10.9%)	283(15.9%)	446(25.0%)	<0.001*	-
Coronary disease	35(2.0%)	35(2.0%)	50(2.8%)	76(4.3%)	<0.001*	-
Smoking					0.227	-
Never	1504(84.4%)	1509(84.7%)	1534(86.0%)	1553(87.1%)		
Former	46(2.6%)	44(2.5%)	44(2.5%)	44(2.5%)		
Current	233(13.1%)	229(12.9%)	205(11.5%)	185(10.4%)		
Drinking					<0.009*	-
Never	1261(70.7%)	1240(69.6%)	1253(70.3%)	1316(73.8%)		
Fomer	393(22.0%)	388(21.8%)	376(21.1%)	313(17.65%)		
Current	129(7.2%)	154(8.6%)	154(8.6%)	153(8.6%)		
Coffee	128(7.2%)	132(7.4%)	122(6.8%)	118(6.6%)	0.802	-
Tea	912(51.1%)	971(54.5%)	945(53.0%)	918(51.5%)	0.291	-

The values are expressed as the mean ± standard deviation, or n (%). Abbreviations: BMI: body mass index, WC: waist circumference, WHtR: waist to height ratio, 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, HbA1c: hemoglobin A1c, ALT: alanine aminotransferase, AST: aspartate aminotransferase, TyG: triglyceride glucose.

All p values for TyG-WHtR index quartiles were determined by using an analysis of variance with the Bonferroni post hoc method. All Z, P trends for TyG-WHtR index quartiles were determined by using a Jonckheere-Terpstra test. * $p < 0.05$. † Q2/Q3/Q4 vs. Q1: $p < 0.001$.

TyG-WHtR and diabetes incidence over 10 years

The analysis revealed that 355 participants developed diabetes during the 10-year follow-up period, with an incidence of n = 27 (1.5%), n = 43 (2.4%), n = 87 (4.9%) and n = 198 (11.1%) in the baseline TyG-WHtR quartiles (Table 1). To adjust for other residual confounders, we performed a Cox regression analysis of diabetes associated with the TyG-WHtR index (Table 2). Model 1 did not include any conditions, and the risk of diabetes showed a gradual upward trend in the TyG-WHtR quartiles (Q2: HR:1.596, 95% CI: 0.987-2.583; Q3: 3.228, 95% CI: 2.095-4.975; Q4: 7.630, 95% CI: 5.104-11.407). In Model 2, we partially adjusted for age and sex: diabetes risk showed a significant increase in TyG-WHtR Q2 (HR: 1.582, 95% CI 0.976-

2.562), Q3 (3.180, 95% CI 2.058-4.914) and Q4 (7.442, 95% CI 4.945-11.201). In Model 3, many factors were considered in the analysis, including age, sex, BMI, HbA1c, family history of diabetes, smoking and drinking. The diabetes risk was significantly higher with increasing TyG-WHtR index quartiles (Q2: 1.421, 95% CI: 0.872-2.315; Q3: 2.563, 95% CI: 1.621-4.052; Q4: 5.185, 95% CI: 3.230, 8.322) and the HR for per 1 unit increase in TyG-WHtR was 2.798. Finally, we found that all models followed the same trend.

Table 2 Correlation between the TyG-WHtR index and diabetes risk

	Per 1 unit increase in TyG-WHtR HR (95%CI)	Q1	Q2 HR (95%CI)	Q3 HR (95%CI)	Q4 HR (95%CI)
Model 1	2.977(2.588,3.425)	Ref	1.596(0.987,2.583)	3.228(2.095,4.975)	7.630(5.104,11.407)
Model 2	2.955(2.558,3.413)	Ref	1.582(0.976,2.562)	3.180(2.058,4.914)	7.442(4.945,11.201)
Model 3	2.798(2.285,3.426)	Ref	1.421(0.872,2.315)	2.563(1.621,4.052)	5.185(3.230,8.322)

Note: Model 1 crude, Model 2 adjusted for gender and age, Model 3 adjusted for sex, age, BMI, HbA1c, smoking, drinking, and family history of diabetes. Abbreviations: TyG-WHtR: triglyceride glucose-waist to height ratio, HR: hazards ratio, CI: confidence intervals.

As illustrated in Figure 1, the aggregate diabetes prevalence differed considerably among the four TyG-WHtR index groups according to the results of a survival statistics study utilizing the Kaplan–Meier survival curve and log-rank test (P < 0.001). Future diabetes risk was significantly increased when the TyG-WHtR index was elevated.

Subgroup analysis

As previously stated, TyG-WHtR is an indicator that can accurately reflect the body's metabolic state. Subgroup comparisons were conducted to assess the effect of additional risk factors on the correlation with the TyG-WHtR index and the future risk of developing diabetes (Table 3). Based on the Centers for Disease Control and Prevention's definition of overweight or obesity in adults, we divided BMI into four groups: underweight, healthy weight, overweight, and obesity[25]. We found a higher risk of diabetes in those older than 80 years (HR: 4.270,95%CI:0.388,46.998), men (HR: 3.087, 95%CI: 2.345,4.064), with BMI <18.5 kg/m2 (HR: 5.611, 95%CI:2.211,14.240) and without hypertension (HR: 2.983, 95%CI: 2.519,3.533). After adjusting for confounders, the age group changed to those aged 41-50 years (HR: 3.773, 95%CI:2.355,6.046, P<0.001), and the results remained unchanged in the other groups.

Table 3 Association of TyG-WHtR with diabetes risk in subgroup analysis

Subgroup	No. of participants	Unadjusted HR (95% CI)	P value	Adjusted HR (95% CI)	P value
Age (years)					
41-50	1854	3.678(2.643,5.120)	<0.001*	3.773(2.355,6.046)	<0.001*
51-60	2425	3.060(2.385,3.926)	<0.001*	3.110(2.193,4.410)	<0.001*
61-70	1899	2.712(2.131,3.451)	<0.001*	2.763(1.931,3.953)	<0.001*
71-80	819	2.355(1.530,3.623)	<0.001*	2.120(1.161,3.872)	0.014*
>80	133	4.270(0.388,46.998)	<0.001*	0	0.909
Gender					
Men	2298	3.087(2.345,4.064)	<0.001*	2.953(1.964,4.441)	<0.001*
Women	4832	2.933(2.490,3.454)	<0.001*	2.924(2.300,3.717)	<0.001*
BMI (kg/m^2)					
<18.5	186	5.611(2.211,14.240)	<0.001*	6.443(1.176,35.300)	0.032*
18.5-24.9	3694	2.550(2.095,3.103)	<0.001*	2.465(1.845,3.292)	<0.001*
25-29.9	2501	3.345(2.654,4.216)	<0.001*	3.353(2.411,4.663)	<0.001*
≥30	749	4.250(2.539,7.114)	<0.001*	3.511(1.521,8.102)	0.003*
Hypertension					
No	6102	2.983(2.519,3.533)	<0.001*	2.983(2.341,3.800)	<0.001*
Yes	1028	2.365 (1.788,3.128)	<0.001*	2.703(1.396,3.079)	<0.001*

Adjusted for gender, age, BMI, HbA1c, smoking, drinking, and family history of diabetes. Abbreviations: HR: Hazard ratios, CI: confidence intervals, BMI: body mass index. * $p < 0.05$.

The ability of the TyG-WHtR index to predict new-onset diabetes

Risk factors were evaluated for its accuracy in anticipating newly diagnosed diabetes using ROC curves (Fig. 2). With an under the curve (AUC) of 0.758 (95% CI: 0.731, 0.785), FBG was found to be the most accurate, and the second most accurate was the TyG-WHtR index (AUC: 0.730, 95% CI: 0.703–0.756). With a best cutoff value of 4.645, TyG-WHtR has 73.52% sensitivity and 62.60% specificity. Compared to BMI, WC, WHtR, TyG-BMI and TyG-WC, the AUC of TyG-WHtR was considerably higher.

Discussion

The incidence of diabetes is currently increasing at an astonishing speed[10]. It was estimated that 10.5% of adults aged 20–79 had diabetes (uncertainty interval: 8.3%–12.0%), with 10.8% of men and 10.2% of women having the condition[3]. The increase in the global burden of diabetes is accompanied by an increase in medical expenditures to treat this disease, which will significantly increase the economic burden on society. Therefore, it is critical to enhance preventive care as well as screening of high-risk groups[26].

Insulin resistance and the failure of beta cells are hallmarks of diabetes[27]. The glucose-clamp approach, which was pioneered by DeFronzo, is widely regarded as the gold standard for quantifying insulin resistance[28]. Unfortunately, this is a time-consuming and pricey approach, so IR is typically measured by less invasive methods, such as the TyG index and obesity-related metrics, including BMI, WC, and WHtR[29,30]. Lim, Jinsook et al. combined the TyG and WHtR indices for the first time and demonstrated that TyG-WHtR outperformed the TyG index alone in assessing insulin resistance[15]. As reported by the ADA, FBG is the gold standard for the diagnosis of diabetes mellitus, so FBG is the strongest predictor of diabetes mellitus[24]. In addition, obese patients have reduced glucose uptake and IR due to elevated free fatty acids in plasma and elevated lipid utilization by muscle[31,32]. These mechanisms promote the development of diabetes mellitus. Therefore, when we combine obesity indicators (BMI, WC, WHtR) with TyG index, their ability to predict diabetes is subsequently enhanced. And between these indicators, TyG-WHtR has the best predictive power. Previous studies have shown an association between diabetes mellitus and the TyG-WHtR index. Compared with other TyG-related parameters, obesity index and lipid ratio, TyG-WHtR has more advantageous in predicting new-onset diabetes in the normoglycemic group as well as in all populations[33]. From August to December 2019, a cross-sectional study of 24,215 normal weight and obese Chinese older adults was conducted in Shenzhen. It found that a higher TyG-WHtR index (AUC: 0.760, 95% CI 0.749-0.771) was remarkably linked with an increased incidence of diabetes, although it was less strongly correlated than the TyG index (AUC: 0.818, 95% CI 0.810–0.825)[16]. This is consistent with our study’s findings.

We also found evidence linking TyG-WHtR to metabolic syndrome. A study assessing IR indicators in metabolic syndrome discovered that TyG-WHtR had the highest AUC for metabolic syndrome identification (AUC: 0.863, 95% CI: 0.828-0.892), which was significantly higher than the TyG index (AUC: 0.796, 95% CI: 0.757-0.831)[19]. Another cross-sectional investigation involving nondiabetic adults found that all of the IR indices studied could identify individuals with metabolic syndrome. The maximum area under the curve for TyG was found to be 0.888 (95% CI: 0.862-0.915), while the AUC for the TyG-WHtR was 0.847 (95% CI: 0.818-0.876)[34]. Thus, diabetes and metabolic syndrome can be accurately predicted by the TyG-WHtR index. Additionally, the index can also predict nonalcoholic fatty liver. Malek, Mojtaba et al. discovered that TyG-WHtR had the highest AUC for detecting NAFLD (0.783, $P < 0.001$), outperforming TyG (AUC: 0.647, $P = 0.002$) and other indices in ROC analysis. Additionally, it was confirmed that the

TyG-WHtR index, which combines TyG and obesity parameters, is more effective at detecting hepatic steatosis than TyG alone[35].

In this study, longitudinal representative cohort data were used to examine the connection between the TyG-WHtR ratio and diabetes. New-onset diabetes was found to be linked to a high TyG-WHtR index, even after correcting for potential related confounders, such as smoking, drinking, and family history of diabetes. Furthermore, in our subgroup analysis, we found that among Chinese > 40 years old, the HR of diabetes gradually decreased with increasing age and was highest in the age group of 41 - 50 years. This may be due to the fact that overweight and obesity rates are rising dramatically, driven by economic development, nutritional transition and sedentary lifestyle, and this trend declined slightly in late adulthood[36,37]. In addition, obesity rates are higher in Chinese men than in women[38]. This may explain the higher prevalence of diabetes in men than in women in this study. As previously reported, in Asian countries such as China and India, where the T2DM incidence is associated with a low BMI at onset, our study confirmed that people with a BMI < 18.5 kg/m^2 are at a much greater risk of having diabetes than those who are obese, overweight or normal[39,40]. As we all know, elevated blood pressure may increase the risk of developing DM by inducing chronic inflammation and endothelial dysfunction[41,42]. Interestingly, the risk of developing TyG-WHtR diabetes was found to be higher in patients without hypertension in this study. This could be due to the demographic and geographic peculiarities of the sampled population.

Some clinically important findings came out of this research. Using TyG-WHtR as a marker for predicting diabetes is the main clinically relevant finding since it can be used to assess an individual’s risk of developing diabetes in the near future. Additionally, this study had a 10-year follow-up period, making the results more relevant. However, this study also has some limitations; the parameters used to calculate TyG-WHtR were collected in 2011, the value of the change in this index over the 10-year period was not available, and we were only able to make a prediction of the future population with diabetes from data from 10 years ago. As a result, additional investigation is required to ascertain the clinical value of TyG-WHtR in individuals with diabetes. In addition, the present study was conducted on a Chinese population. And the known race-specific body composition in East Asians may limit the generalizability of these results to other populations.

Conclusions

Using longitudinal representative cohort data, we demonstrated a substantial increase in diabetes risk as the TyG-WHtR increased. Our findings indicate that the TyG-WHtR score, a proxy indicator for IR, is a valid and reliable indicator of risk for the development of diabetes.

Declarations

Ethics approval and consent to participate

The study was performed in accordance with the Declaration of Helsinki and approved by the Research Ethics Committees of Rui-Jin Hospital affiliated with Jiao-Tong University School of Medicine. Approval number: 201,114. And everyone who took part in this research offered informed written consent before participating. The original data obtained from the database used in this paper were approved.

Consent for publication

Not Applicable.

Availability of data and materials

Data supporting the results reported in the manuscript is not applicable, but it can be obtained by contacting the corresponding author.

Declarations of interest

None.

Founding

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Author's Contributions

All of the authors contributed to the discussion and manuscript preparation. Jie Lin and Jing Gui contributed equally to this work, organized the data collaboration, interpreted the statistical analyses, and wrote the article; Xin Xiang checked the multiple-site data; Qin Wan designed the study. All authors read and approved the final manuscript.

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Figures

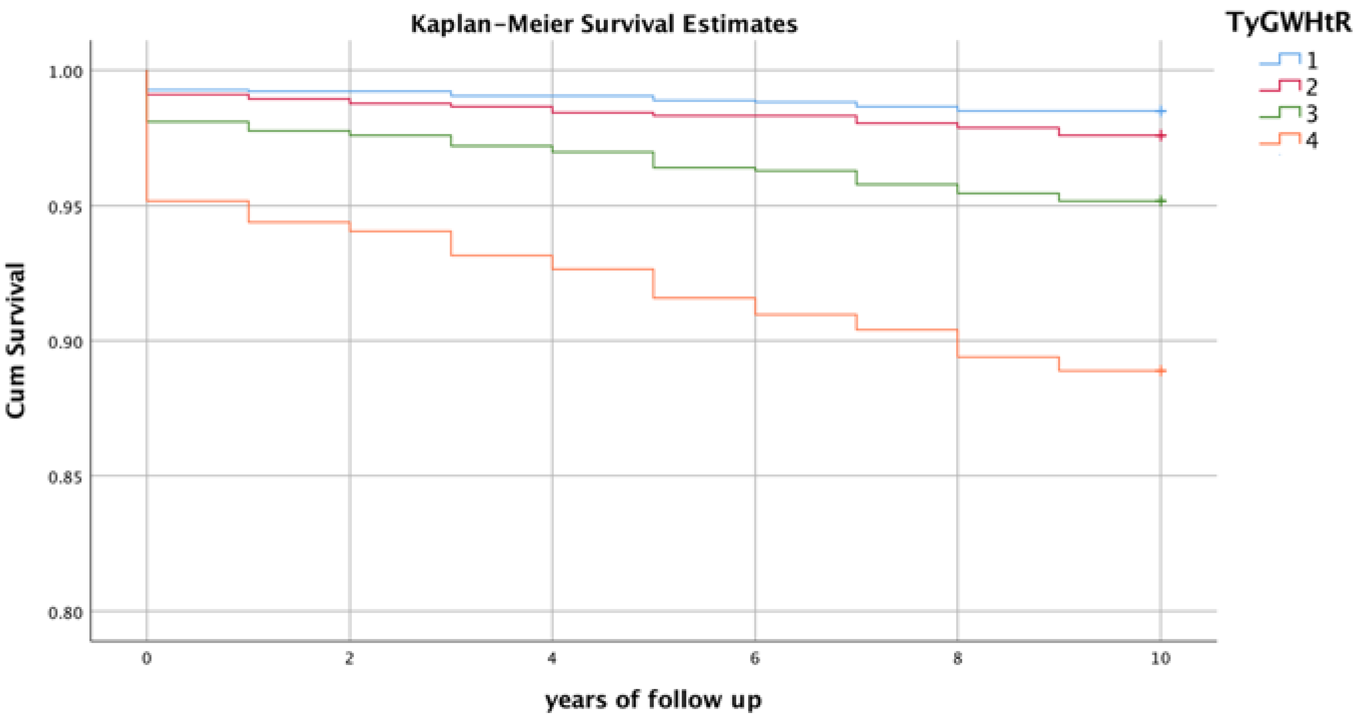

Figure 1

Kaplan–Meier estimates of the risk of developing diabetes stratified by quartiles of the TyG-WHtR index ($P < 0.001$). Abbreviations: TyG-WHtR: triglyceride glucose-waist to height ratio.

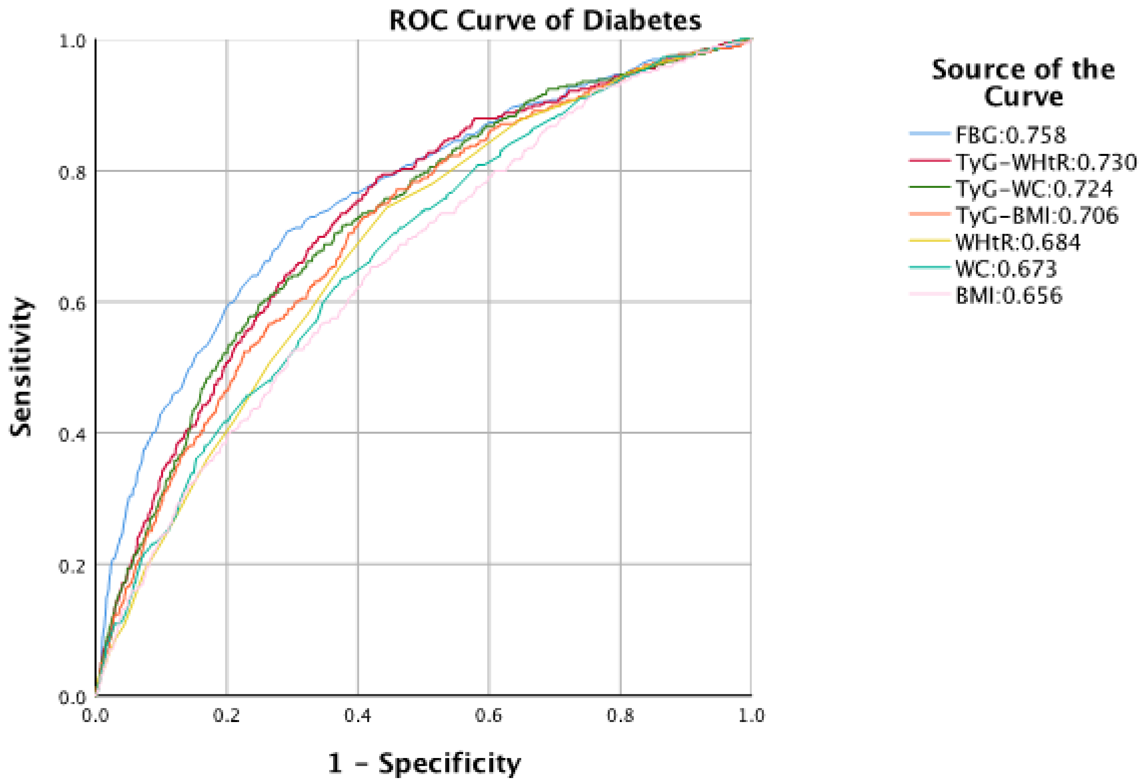

Figure 2

ROC analysis to predict diabetes. Abbreviations: ROC: receiver operating characteristic, FPG: fasting plasma glucose, TyG: triglyceride glucose, TyG-WHtR: triglyceride glucose-waist to height ratio, TyG-WC: triglyceride glucose-waist circumference, TyG-BMI: triglyceride glucose-body mass index, WHtR: triglyceride glucose-waist to height ratio, WC: waist circumference, BMI: body mass index.