

Prediction Value of Visceral Obesity Related Indices for Visceral Obesity in Chinese Patients with Type 2 Diabetes Mellitus

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Purpose: Visceral obesity (VO) has a significant impact on the progression of type 2 diabetes mellitus (T2DM) and insulin resistance. This study aims to evaluate the correlation and predictive utility of visceral obesity-related indices in T2DM patients with VO.

Patients and Methods: This study included 2438 Chinese patients with T2DM. Visceral fat area (VFA) was assessed using bioelectrical impedance analysis (BIA), with VFA ≥ 80 cm² defined as VO. Multifactor logistic regression analysis was used to explore the relationship between VO and various indices in T2DM patients, including the Chinese visceral adiposity index (CVAI), metabolic score for visceral fat (METS-VF), new visceral adiposity index (NVAI), visceral adiposity index (VAI), waist circumference (WC), body mass index (BMI), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR). Receiver operating characteristic (ROC) curves were plotted, and the area under the curve (AUC) was used to evaluate the ability of these indices to screen for VO in T2DM subjects. Pearson correlation analysis was performed to analyze the correlation between these indices and VFA.

Results: 1226 (50.29%) T2DM patients were found to have VO. The prevalence of VO was higher in males than in females. Among the total population, WC had the best predictive performance for VO (AUC=0.8833, optimal cutoff=90.05). CVAI was the best predictor for males (AUC=0.8837, optimal cutoff=117.39), while WC performed best in females (AUC=0.8733, optimal cutoff=87.25). Among individuals with normal WC, CVAI for males and METS-VF for females had the best predictive performance for VO.

Conclusion: There exists a strong correlation between VO and its related indicators in patients with T2DM. WC, CVAI, and METS-VF are optimal predictive indices for VO in this patient population.

Keywords: visceral obesity, visceral obesity related indices, type 2 diabetes mellitus

Introduction

In the year 2019, the International Diabetes Federation made an estimation that around 463 million people globally were affected by diabetes mellitus, a figure projected to rise to 700 million by 2045, with type 2 diabetes mellitus (T2DM) accounting for 90% of these cases.¹ The growing rates of both prevalence and incidence of T2DM are greatly affected by the increase in obesity, a significant risk element influencing both the onset and progression of the condition.² Obesity refers to an excessive buildup of body fat, this can be classified into two main groups: generalized obesity and abdominal obesity, based on how the fat is distributed. The accumulation of abdominal fat consists of two major elements: the subcutaneous fat area (SFA) and the visceral fat area (VFA).³ Visceral adipose tissue, which is a type of white adipose tissue, is distinguished by its bigger fat cells that demonstrate elevated metabolic activity and heightened insulin resistance (IR). Conversely, the adipose tissue found just under the skin is characterized by smaller fat cells. Compared to VFA, SFA has a relatively lesser effect on IR.⁴⁻⁶ Significantly, Visceral obesity (VO), a specific form of obesity, is recognized as a unique risk element for T2DM and

associated complications, while also elevating the likelihood of mortality from various causes.^{7,8} Consequently, timely and accurate assessment of VO is essential for early intervention.

At present, measuring the VFA is primarily regarded as being best assessed through magnetic resonance imaging (MRI) and computed tomography (CT).⁹ While MRI does not expose patients to radiation, its examination costs can be prohibitively high. Conversely, CT is associated with radiation hazards and similarly high costs. Bioelectrical impedance analysis (BIA) presents an easy, non-invasive, and affordable option for evaluating body composition.¹⁰ Correlation analyses indicate that BIA can serve as a viable substitute for CT in certain contexts.^{11,12} However, BIA requires professional operation and is not always convenient, which can restrict the timing and location of measurements.¹³ As a result, there is a significant demand for discovering more user-friendly indicators for efficient screening.

Traditionally, the Body Mass Index (BMI), is a measurement used in anthropology, has served as a common approach for assessing a person's metabolic health. Nevertheless, it does not take into account factors other than height (HT) and weight (WT), including muscle and fat distribution.⁸ In contrast, waist circumference (WC) demonstrates a stronger correlation with VO. Nonetheless, WC also lacks the ability to differentiate between VFA and SFA.¹⁴ In conclusion, while both WC and BMI serve as significant tools for assessing obesity, they do not comprehensively reflect an individual's health risk nor adequately assess the accumulation of VO.¹⁵ Consequently, it is crucial to pursue additional indicators.

In recent years, several indices for assessing VO, including the Chinese visceral adiposity index (CVAI),¹⁶ the metabolic score for visceral fat (METS-VF),¹⁷ the new visceral adiposity index (NVAI),¹⁸ and the visceral adiposity index (VAI),¹⁹ have been introduced based on diverse populations across various countries. These indices have demonstrated a superior ability to predict VO when compared to conventional methods. Nevertheless, there remains a paucity of studies examining the correlation between different visceral adiposity indices and VO in Patients with T2DM. Consequently, our research seeks to assess the efficacy of these visceral adiposity indices in predicting VO and to identify their respective optimal cut-off values.

Materials and Methods

Study Population

The data for this study was acquired from the National Standardized Metabolic Management Center (MMC) at Changde Hospital, which is part of Xiangya School of Medicine, Central South University, covering the period from May 1, 2020, to October 31, 2023. This cross-sectional research encompassed 3,193 individuals diagnosed with T2DM, all above 18 years of age. The exclusion criteria included: 1) Diagnosis of type 1 diabetes mellitus or other particular diabetes types mellitus; 2) Recent acute diabetic complications or severe infections occurring within the prior month; 3) Pregnancy or breastfeeding; 4) Incomplete information concerning high-density lipoprotein cholesterol (HDL-C), HT, WT, age, triglycerides (TG), systolic blood pressure (SBP) and diastolic blood pressure (DBP), WC, triglycerides (TG), VFA, or fasting plasma glucose (FPG); 5) Presence of malignant tumors or cachexia; 6) Serious liver or immune system diseases; 7) End-stage diabetic nephropathy. In total, 2,438 T2DM patients were ultimately retained for the study.

Laboratory and Anthropometry

Data for all variables were collected and documented by researchers who had received proper training, employing standardized questionnaires. These questionnaires encompassed general clinical information, including general clinical data such as gender, age, smoking (never, former, everyday), drinking (never, former, everyday), engagement in moderate-intensity physical activity (MIPA), Course of diabetes, history of hypertension, hyperlipidemia, hyperuricemia, as well as the use of drugs for hypertension, hyperlipidemia, and hyperuricemia, and history of cancer. HT and WT were assessed after participants had removed their heavy clothing and shoes. Hip circumference (Hip) and WC were assessed with a non-elastic tape; WC was measured at the halfway point between the lower boundary of the rib cage and the iliac crest, following the mid-axillary line, while the hip was assessed at the location of maximum hip extension. Following a 5–10minute resting period in a quiet setting, SBP and DBP were collected from participants while they were seated, utilizing a standard mercury sphygmomanometer, following the established procedures. All measurements were rigorously executed in alignment with national.

After a 10–12 hour fast, fasting venous blood samples were collected. The biochemical markers analyzed using the fully automated biochemical analyzer (AS-2450) encompassed aspartate aminotransferase (AST), TG, total cholesterol (TC), HDL-C, low-density lipoprotein cholesterol (LDL-C), FPG, 2-hour postprandial glucose (PPG), alanine aminotransferase (ALT), serum creatinine (Scr), and uric acid (UA). Glycated hemoglobin (HbA1c) was measured using the fully automated glycated hemoglobin analyzer (AILEX AH-600). The estimated glomerular filtration rate (eGFR) was determined using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation, as outlined below: Females: $\text{Scr} \leq 0.7 \text{ mg/dL}$, $\text{eGFR} = 151 \times (\text{Scr}/0.7)^{-0.328} \times 0.993^{\text{age}}$; $\text{Scr} > 0.7 \text{ mg/dL}$, $\text{eGFR} = 151 \times (\text{Scr}/0.7)^{-1.210} \times 0.993^{\text{age}}$; Males: $\text{Scr} \leq 0.9 \text{ mg/dL}$, $\text{eGFR} = 149 \times (\text{Scr} / 0.9)^{-0.411} \times (0.993)^{\text{age}}$; $\text{Scr} > 0.9 \text{ mg/dL}$, $\text{eGFR} = 149 \times (\text{Scr}/0.9)^{-1.210} \times 0.993^{\text{age}}$. Age and Scr are expressed in years and mg/dL, respectively.²⁰

Measurement of Abdominal Fat Area

The assessment of VFA and SFA took place following a fasting duration that lasts at least 12 hours for the subjects, utilizing BIA (HDS-2000 DUALSCAN; Omron Healthcare, Kyoto, Japan) performed by a qualified physician.²¹ The patients are advised to fast starting at 20:00 on the evening prior to the examination. They should lie flat on their backs and have the skin on their wrists, ankles, and abdomen exposed. Additionally, hand and foot electrode clips along with an abdominal electrode belt should be secured. After ensuring the patient is calm, they are guided to hold their breath, during which VFA and SFA measurements are taken.

Definition and Diagnosis

T2DM diagnosis: typical diabetes symptoms plus random blood glucose $\geq 11.1 \text{ mmol/l}$; Or add FPG $\geq 7.0 \text{ mmol/l}$; Or add glucose load for 2h blood glucose $\geq 11.1 \text{ mmol/l}$; Or add HbA1c $\geq 6.5\%$.²² If the subject has a DBP $\geq 90 \text{ mmHg}$ or an SBP $\geq 140 \text{ mmHg}$ or is undergoing antihypertensive treatment, they are diagnosed with hypertension.²³ Physical activity of moderate intensity is characterized by participating in more than 150 minutes of exercise weekly, which varies from moderate to vigorous intensity levels.²⁴ As per the diagnostic guidelines for obesity among Chinese adults, BMI of 28 kg/m^2 or higher is classified as obesity, while a WC $\geq 90 \text{ cm}$ (male) and $\geq 85 \text{ cm}$ (female) indicates central obesity.²⁵ Diagnostic criteria for VO: VFA $\geq 80 \text{ cm}^2$.²⁶

Calculation Formula

$$\text{BMI} = \text{WT (kg)} / [\text{HT(m)}]^2$$

$$\text{Waist-to-hip ratio (WHR)} = \text{WC (cm)} / \text{Hip(cm)}$$

$$\text{Waist-to-height ratio (WHtR)} = \text{WC (cm)} / \text{HT (cm)}$$

$$\text{METS-IR} = \text{Ln} [2 \times \text{FBG (mg/dl)} + \text{TG (mg/dl)}] \times \text{BMI (kg/m}^2) / \text{Ln} [\text{HDL-C(mg/dl)}]$$

$$\text{MBP (mean blood pressure)} = 2/3\text{DBP (mmHg)} + 1/3\text{SBP (mmHg)}$$

$$\text{METS-VF(Male)} = 4.466 + 0.011 \times (\text{Ln (METS-IR)})^3 + 3.239 \times (\text{Ln (WHtR)})^3 + 0.139 \times 1 + 0.594 \times (\text{Ln (Age(years))})$$

$$\text{METS-VF(Female)} = 4.466 + 0.011 \times (\text{Ln (METS-IR)})^3 + 3.239 \times (\text{Ln (WHtR)})^3 + 0.139 \times 0 + 0.594 \times (\text{Ln (Age(years))})$$

$$\text{CVAI(Male)} = -267.93 + 0.68 \times \text{age(years)} + 0.03 \times \text{BMI (kg/m}^2) + 4.00 \times \text{WC (cm)} + 22.00 \times \text{LgTG(mmol/L)} - 16.32 \times \text{HDL-C (mmol/L)}$$

$$\text{CVAI(Female)} = -187.32 + 1.71 \times \text{age(years)} + 4.23 \times \text{BMI (kg/m}^2) + 1.12 \times \text{WC (cm)} + 39.76 \times \text{LgTG (mmol/L)} - 11.66 \times \text{HDL-C (mmol/L)}$$

$$\text{NVAI(Male)} = 1 / [1 + \exp \{-(21.858 + (0.099 \times \text{age(years)}) + (0.10 \times \text{WC (cm)}) + (0.12 \times \text{MBP (mmHg)}) + (0.006 \times \text{TG (mmol/L)}) + (-0.077 \times \text{HDL (mmol/L)}))\}]$$

$$\text{NVAI(Female)} = 1 / [1 + \exp \{-(18.765 + (0.058 \times \text{age(years)}) + (0.14 \times \text{WC (cm)}) + (0.057 \times \text{MBP (mmHg)}) + (0.004 \times \text{TG (mmol/L)}) + (-0.057 \times \text{HDL (mmol/L)}))\}]$$

$$\text{VAI(Male)} = [\text{WC (cm)} / (39.68 + 1.88 \times \text{BMI (kg/m}^2))] \times (\text{TG (mmol/L)} / 1.03) \times (1.31 / \text{HDL-C (mmol/L)})$$

$$\text{VAI(Female)} = [\text{WC (cm)} / (36.58 + 1.89 \times \text{BMI (kg/m}^2))] \times (\text{TG (mmol/L)} / 0.81) \times (1.52 / \text{HDL-C (mmol/L)})$$

Statistical Analysis

Continuous variables are represented as mean \pm standard deviation or median (with quartiles: Q1, Q3). To assess differences between groups, independent sample t-tests or Mann-Whitney *U*-tests are employed. Frequency (percentage) represents categorical variables, and group differences were evaluated using the chi-square test or Fisher's exact test. To analyze the correlation between indices related to visceral obesity and VO in individuals with T2DM, Pearson's correlation coefficient was employed. Multifactorial logistic regression was employed to examine the connection between indices related to visceral obesity and VO in individuals diagnosed with T2DM. Additionally, the visceral obesity-related indices were categorized into quartiles, and trend p-values were then calculated. The Receiver Operating Characteristic (ROC) curve is generated, and the Area Under the Curve (AUC) is computed in order to assess the predictive performance. To determine the best index cutoff value of visceral obesity-related index in predicting VO in T2DM patients and the corresponding sensitivity and specificity. Moreover, all statistical analyses were conducted using Empower Stats (R) version 4.2, and a P-value of under 0.05 was considered statistically significant in a two-tailed context.

Results

Baseline Characteristics of Participants

In this study, 2,438 patients diagnosed with T2DM were analyzed, with 1,226 (50.29%) of them exhibiting concurrent VO. Among these individuals, 813 were male (66.31%) and 413 were female (32.69%). Participants had an average age of 53.09 \pm 10.78 years. As detailed in Table 1, individuals suffering from T2DM and concurrent VO demonstrated elevated levels of DBP, SBP, MBP, BMI, WC, SFA, HbA1c, FPG, PPG, ALT, AST, TG, UA, LDL-C, WHR, WHtR, VAI, CVAI, NVAI, and METS-VF. Additionally, these patients were found to be predominantly male and exhibited a greater frequency of smoking, alcohol use, and a background of hyperuricemia, hyperlipidemia, hypertension, as well as treatment for hyperuricemia and hypertension. Conversely, patients without VO had comparatively higher levels of HDL-C.

Table 1 Baseline Characteristics of Participants

VAT Categorical	Total	Non-VO	VO	P-value
N		1212	1226	
AGE (years)	53.09 \pm 10.78	53.60 \pm 10.11	52.59 \pm 11.39	0.021
SBP ((mmHg)	137.91 \pm 20.04	135.27 \pm 20.13	140.51 \pm 19.61	<0.001
DBP ((mmHg)	84.53 \pm 11.59	81.96 \pm 11.04	87.07 \pm 11.56	<0.001
MBP (mmHg)	102.32 \pm 12.96	99.73 \pm 12.67	104.88 \pm 12.75	<0.001
BMI ((kg/m ²)	25.35 \pm 3.53	23.29 \pm 2.43	27.40 \pm 3.26	<0.001
WC (cm)	89.66 \pm 10.33	83.14 \pm 7.55	96.10 \pm 8.50	<0.001
SFA (cm ²)	175.47 \pm 62.22	140.90 \pm 46.10	209.65 \pm 56.99	<0.001
DMCOURSE (month)	49.00 (17.00–104.00)	52.00 (19.00–109.00)	48.00 (15.00–96.00)	0.245
HbA1c (%)	7.50 (6.50–9.30)	7.20 (6.30–9.00)	7.80 (6.70–9.70)	<0.001
FPG (mmol/L)	7.70 (6.39–9.85)	7.43 (6.16–9.40)	7.99 (6.62–10.30)	<0.001
PPG (mmol/L)	13.56 \pm 5.19	13.15 \pm 5.20	13.98 \pm 5.15	<0.001
ALT (U/L)	24.00 (17.00–38.00)	21.00 (15.00–29.00)	29.00 (20.00–47.50)	<0.001
AST (U/L)	23.00 (18.00–29.00)	21.00 (18.00–25.00)	25.00 (20.00–33.00)	<0.001

(Continued)

Table 1 (Continued).

VAT Categorical	Total	Non-VO	VO	P-value
UA ($\mu\text{mol/L}$)	336.83 \pm 87.17	319.21 \pm 84.72	354.38 \pm 86.06	<0.001
eGFR (mL/min/1.73m^2)	107.03 \pm 20.96	106.91 \pm 18.49	107.14 \pm 23.16	0.787
TG (mmol/L)	1.83 (1.27–2.81)	1.51 (1.09–2.25)	2.17 (1.52–3.27)	<0.001
TC (mmol/L)	4.98 \pm 1.23	4.95 \pm 1.19	5.01 \pm 1.26	0.195
HDL-C (mmol/L)	1.32 \pm 0.35	1.41 \pm 0.37	1.22 \pm 0.30	<0.001
LDL-C (mmol/L)	2.78 \pm 0.88	2.72 \pm 0.90	2.85 \pm 0.86	<0.001
WHR	0.93 \pm 0.07	0.90 \pm 0.06	0.97 \pm 0.06	<0.001
WHtR	0.56 \pm 0.06	0.52 \pm 0.05	0.59 \pm 0.05	<0.001
VAI	2.35 (1.48–3.81)	1.84 (1.16–2.91)	2.94 (1.96–4.64)	<0.001
CVAI	127.99 \pm 38.63	106.58 \pm 31.97	149.15 \pm 32.49	<0.001
NVAI	0.97 (0.87–0.99)	0.92 (0.72–0.98)	0.99 (0.96–1.00)	<0.001
METS-VF	6.86 (6.53–7.13)	6.60 (6.25–6.84)	7.10 (6.88–7.29)	<0.001
Sex				<0.001
Male	1396 (57.26%)	583 (48.10%)	813 (66.31%)	
Female	1042 (42.74%)	629 (51.90%)	413 (33.69%)	
History of hypertension				<0.001
No	1640 (67.60%)	917 (75.91%)	723 (59.36%)	
Yes	786 (32.40%)	291 (24.09%)	495 (40.64%)	
Hypertension drugs				<0.001
No	1735 (71.55%)	955 (79.06%)	780 (64.09%)	
Yes	690 (28.45%)	253 (20.94%)	437 (35.91%)	
History of hyperuricemia				<0.001
No	2328 (96.00%)	1185 (98.10%)	1143 (93.92%)	
Yes	97 (4.00%)	23 (1.90%)	74 (6.08%)	
Hyperuricemia drugs				<0.001
No	2388 (98.56%)	1204 (99.67%)	1184 (97.45%)	
Yes	35 (1.44%)	4 (0.33%)	31 (2.55%)	
History of hyperlipidemia				<0.001
No	1750 (72.16%)	937 (77.57%)	813 (66.80%)	
Yes	675 (27.84%)	271 (22.43%)	404 (33.20%)	
Hyperlipidemia drugs				<0.001
No	2093 (86.45%)	1087 (89.98%)	1006 (82.93%)	
Yes	328 (13.55%)	121 (10.02%)	207 (17.07%)	

(Continued)

Table 1 (Continued).

VAT Categorical	Total	Non-VO	VO	P-value
Smoking				<0.001
Never	1751 (72.24%)	914 (75.72%)	837 (68.78%)	
Former	130 (5.36%)	58 (4.81%)	72 (5.92%)	
Everyday	543 (22.40%)	235 (19.47%)	308 (25.31%)	
Drinking				<0.001
Never	1788 (73.76%)	969 (80.35%)	819 (67.24%)	
Former	473 (19.51%)	196 (16.25%)	277 (22.74%)	
Everyday	163 (6.72%)	41 (3.40%)	122 (10.02%)	
MIPA				0.003
No	2326 (96.24%)	1141 (95.08%)	1185 (97.37%)	
Yes	91 (3.76%)	59 (4.92%)	32 (2.63%)	

Abbreviations: BMI, body mass index; WC, waist circumference; SFA, subcutaneous fat area; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; PPG, postprandial plasma glucose; HbA1c, glycated hemoglobin; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; ALT, alanine aminotransferase; AST, aspartate aminotransferase; eGFR, estimated Glomerular Filtration Rate; CVAI, Chinese visceral adiposity index; METS-VF, Metabolic score for viscera fat; NVAI, new visceral adiposity index; VAI, visceral adiposity index; WHR, Waist-to-hip ratio; WHtR, Waist-to-height ratio; MIPA, engagement in moderate-intensity physical activity.

Research on the Connection Between Indices Related to Visceral Obesity and VFA

The Pearson analysis evaluates the relationship between indices of obesity and VFA. [Table 2](#) shows a positive relationship between the VFA and various indices associated with VO. Specifically, WC, BMI, CVAI, and WHtR are significantly correlated with VFA, with r values of 0.7865, 0.7536, 0.7233, and 0.7215, respectively. Among males, CVAI, WC, BMI, and WHtR are significantly correlated with VFA, with r values of 0.7983, 0.7915, 0.7536, and 0.7215, respectively. Among females, WC, WHtR, BMI, and CVAI are significantly correlated with VFA, with r values of 0.7707, 0.7434, 0.7531, and 0.7104, respectively. All correlations are statistically significant at P < 0.001.

Table 2 The Association Between Visceral Obesity Related Indices and VO Area

Variable	ALL		Male		Female	
	Correlation	P value	Correlation	P value	Correlation	P value
VAI	0.2364	<0.001	0.2582	<0.001	0.2133	<0.001
CVAI	0.7233	<0.001	0.7983	<0.001	0.7104	<0.001
METS-VF	0.6651	<0.001	0.6638	<0.001	0.6623	<0.001
NVAI	0.4598	<0.001	0.3466	<0.001	0.5657	<0.001
BMI	0.7536	<0.001	0.7639	<0.001	0.7351	<0.001
WC	0.7865	<0.001	0.7915	<0.001	0.7707	<0.001
WHR	0.5862	0.0001	0.5983	<0.001	0.5347	<0.001
WHtR	0.7215	<0.001	0.7658	<0.001	0.7434	<0.001

The Connection Between Indices Related to Visceral Obesity and VO in Individuals with T2DM

A multivariate logistic regression analysis was utilized to investigate the connection between indicators related to visceral obesity and VO in individuals diagnosed with T2DM. For this research, the indices pertaining to VO were transformed into Z-scores for the purpose of analysis. Table 3 illustrates that, following a comprehensive adjustment for confounding

Table 3 Logistic Regression Analysis of the Relationship Between Visceral Obesity-Related Indices and Visceral Obesity

Exposure	Non-Adjusted	Adjust I	Adjust II
CVAI Z-score	5.77 (4.96, 6.71) <0.0001	11.02 (9.02, 13.47) <0.0001	9.87 (7.91, 12.30) <0.0001
CVAI quartile			
Q1	1.0	1.0	1.0
Q2	3.32 (2.51, 4.41) <0.0001	5.79 (4.24, 7.91) <0.0001	5.30 (3.77, 7.45) <0.0001
Q3	10.47 (7.90, 13.87) <0.0001	25.73 (18.37, 36.05) <0.0001	22.35 (15.40, 32.44) <0.0001
Q4	47.00 (33.53, 65.88) <0.0001	165.52 (108.06, 253.54) <0.0001	132.84 (82.95, 212.73) <0.0001
P for trend	<0.0001	<0.0001	<0.0001
VAI Z-score	1.86 (1.62, 2.14) <0.0001	1.93 (1.66, 2.23) <0.0001	1.53 (1.32, 1.77) <0.0001
VAI quartile			
Q1	1.0	1.0	1.0
Q2	2.87 (2.25, 3.67) <0.0001	3.33 (2.57, 4.31) <0.0001	2.90 (2.17, 3.87) <0.0001
Q3	4.77 (3.73, 6.10) <0.0001	5.99 (4.61, 7.80) <0.0001	5.00 (3.72, 6.72) <0.0001
Q4	6.81 (5.29, 8.77) <0.0001	8.67 (6.60, 11.40) <0.0001	6.40 (4.68, 8.75) <0.0001
P for trend	<0.0001	<0.0001	<0.0001
METS-VF Z-score	7.51 (6.33, 8.90) <0.0001	10.77 (8.80, 13.18) <0.0001	8.68 (7.00, 10.78) <0.0001
METS-VF quartile			
Q1	1.0	1.0	1.0
Q2	3.96 (2.94, 5.33) <0.0001	4.81 (3.50, 6.60) <0.0001	3.99 (2.82, 5.65) <0.0001
Q3	13.50 (10.03, 18.16) <0.0001	19.61 (14.08, 27.30) <0.0001	15.80 (11.03, 22.63) <0.0001
Q4	69.78 (48.49, 100.43) <0.0001	136.18 (89.71, 206.72) <0.0001	86.76 (55.67, 135.22) <0.0001
P for trend	<0.0001	<0.0001	<0.0001
NVAI Z-score	4.68 (3.87, 5.66) <0.0001	6.63 (5.23, 8.40) <0.0001	5.86 (4.48, 7.66) <0.0001
NVAI quartile			
Q1	1.0	1.0	1.0
Q2	3.42 (2.63, 4.44) <0.0001	5.35 (4.01, 7.13) <0.0001	5.06 (3.64, 7.02) <0.0001
Q3	7.40 (5.68, 9.64) <0.0001	15.95 (11.54, 22.06) <0.0001	14.34 (9.89, 20.78) <0.0001
Q4	18.22 (13.68, 24.26) <0.0001	53.47 (36.33, 78.70) <0.0001	41.06 (26.31, 64.08) <0.0001

(Continued)

Table 3 (Continued).

Exposure	Non-Adjusted	Adjust I	Adjust II
P for trend	<0.0001	<0.0001	<0.0001
WC Z-score	10.39 (8.61, 12.55) <0.0001	10.55 (8.68, 12.83) <0.0001	8.94 (7.25, 11.01) <0.0001
WC quartile			
Q1	1.0	1.0	1.0
Q2	5.94 (4.20, 8.39) <0.0001	5.94 (4.19, 8.43) <0.0001	5.00 (3.44, 7.26) <0.0001
Q3	24.71 (17.51, 34.86) <0.0001	24.63 (17.34, 34.99) <0.0001	20.31 (13.99, 29.49) <0.0001
Q4	164.64 (106.64, 254.18) <0.0001	164.50 (105.38, 256.78) <0.0001	117.06 (72.39, 189.30) <0.0001
P for trend	<0.0001	<0.0001	<0.0001
BMI Z-score	7.51 (6.36, 8.87) <0.0001	7.75 (6.53, 9.21) <0.0001	6.90 (5.73, 8.32) <0.0001
BMI quartile			
Q1	1.0	1.0	1.0
Q2	4.11 (3.04, 5.56) <0.0001	3.80 (2.80, 5.17) <0.0001	3.13 (2.25, 4.34) <0.0001
Q3	13.15 (9.75, 17.75) <0.0001	12.16 (8.95, 16.51) <0.0001	9.85 (7.07, 13.71) <0.0001
Q4	72.72 (50.53, 104.66) <0.0001	75.84 (52.08, 110.44) <0.0001	53.34 (35.57, 79.97) <0.0001
P for trend	<0.0001	<0.0001	<0.0001
WHR Z-score	3.99 (3.51, 4.54) <0.0001	3.84 (3.36, 4.38) <0.0001	3.20 (2.77, 3.68) <0.0001
WHR quartile			
Q1	1.0	1.0	1.0
Q2	3.05 (2.30, 4.06) <0.0001	2.95 (2.21, 3.94) <0.0001	2.40 (1.74, 3.30) <0.0001
Q3	7.97 (6.10, 10.42) <0.0001	7.48 (5.67, 9.86) <0.0001	6.11 (4.52, 8.25) <0.0001
Q4	26.66 (19.61, 36.24) <0.0001	24.77 (18.05, 34.00) <0.0001	17.30 (12.22, 24.47) <0.0001
P for trend	<0.0001	<0.0001	<0.0001
WHtR Z-score	6.53 (5.58, 7.63) <0.0001	7.89 (6.64, 9.38) <0.0001	6.67 (5.55, 8.02) <0.0001
WHtR quartile			
Q1	1.0	1.0	1.0
Q2	4.06 (2.91, 5.68) <0.0001	4.08 (2.89, 5.76) <0.0001	3.31 (2.28, 4.80) <0.0001
Q3	12.66 (9.24, 17.36) <0.0001	14.15 (10.18, 19.67) <0.0001	11.52 (8.09, 16.40) <0.0001
Q4	56.72 (40.17, 80.08) <0.0001	79.80 (55.12, 115.54) <0.0001	54.23 (36.48, 80.62) <0.0001
P for trend	<0.0001	<0.0001	<0.0001

Notes: Non-adjusted model adjust for: None. Adjust I model adjust for: SEX; AGE; Course of diabetes; smoking; drinking; Adjust II model adjust for: SEX; AGE; Course of diabetes; smoking; drinking; history of hypertension, history of hyperlipidemia, history of hyperuricemia, Hypertension drugs, hyperlipidemia drugs, hyperuricemia drugs; LDLC; PPG; ALT; AST; UA; HbA1c; MIPA.

variables, the adjusted odds ratios (OR) associated with each standard deviation (SD) increment in CVAI, VAI, METS-VF, NVAI, WC, BMI, WHR, and WHtR are 6.10 (95% CI: 5.09, 7.30), 1.41 (95% CI: 1.23, 1.60), 6.96 (95% CI: 5.73, 8.46), 4.46 (95% CI: 3.54, 5.62), 8.82 (95% CI: 7.18, 10.84), 6.52 (95% CI: 5.43, 7.83), 3.20 (95% CI: 2.78, 3.68), and

6.02 (95% CI: 5.05, 7.17), in that order. In Model II, when the indices related to visceral obesity were categorized into quartiles, the first group acted as the reference. The OR for the fourth group concerning visceral obesity-related indices exhibited an increasing trend in comparison to the reference group ($p < 0.001$). The findings suggest that aspects related to visceral fat could function as separate risk factors for VO in those diagnosed with T2DM.

Predictive Capacity of Indices Related to Visceral Obesity for VO

As illustrated in Table 4 and Figure 1, among the indices related to visceral obesity, WC attained an AUC of 0.8833 (95% CI: 0.8704–0.8962), representing the highest performance in predicting VO, using a cutoff threshold of 90.05 (specificity: 0.8276; sensitivity: 0.7773). For the male population, as shown in Table 5 and Figure 2, CVAI demonstrated a notable AUC of 0.8837 (95% CI: 0.8665–0.9009) when it came to predicting VO, with a threshold set at 117.3900 (sensitivity: 0.8266; specificity: 0.7839), as indicated in Table 6 and illustrated in Figure 3, WC exhibited the highest AUC of 0.8733 (95% CI: 0.8524–0.8943) for predicting VO, with a threshold value established at 87.2500 (specificity: 0.7822; sensitivity: 0.8015).

Predictive Effectiveness of Visceral Obesity-Related Indices on VO in Patients with Normal WC

In the population of individuals with T2DM who have a normal WC, the findings in Table 7 and Figure 4 indicate that the CVAI exhibits the highest AUC for predicting VO in males, measuring 0.7323 (95% CI: 0.6850–0.7796), with a critical threshold of 92.4350 (Specificity: 0.6150; Sensitivity: 0.7656). Conversely, Table 8 and Figure 5 demonstrate that among females, the METS-VF achieves the highest AUC for predicting VO, recorded at 0.7311 (95% CI: 0.6675–0.7947), with a threshold value established at 6.4733 (specificity: 0.6028; sensitivity: 0.7857).

Discussion

This research illustrates that males show a higher level of VO as well as a greater incidence of VO. The metrics associated with visceral obesity have a positive correlation with VO in individuals suffering from T2DM, and this relationship continues to be significant even when accounting for confounding factors using multiple logistic regression analysis. This study demonstrates that WC can serve as a simple and effective indicator for identifying VO among patients with T2DM. Moreover, further statistical evaluations indicate that in populations exhibiting normal WC, CVAI and METS-VF serve as the most dependable measures for forecasting VO in male and female patients with T2DM.

Research conducted previously has demonstrated that the distribution of fat tissue varies by gender, as women generally exhibit a larger percentage of subcutaneous fat, whereas men tend to have a higher quantity of VO.²⁷ Aligned with these results, our research additionally indicates that males possess a greater percentage of VO and an increased prevalence of VO. The notable variations in fat tissue characteristics related to gender are primarily affected by sex hormones, aging processes, and genetic determinants.^{28–30} Research indicates that estrogen promotes the accumulation of

Table 4 Predictive Ability of Visceral Obesity Related Indices for VO

Test	AUC	95% CI low	95% CI upp	Threshold	Specificity	Sensitivity
VAI	0.6931	0.6723	0.7139	1.9150	0.5231	0.7684
METS-VF	0.8530	0.8384	0.8677	6.9168	0.8267	0.7202
NVAI	0.7767	0.7585	0.7950	0.9655	0.6691	0.7480
CVAI	0.8334	0.8177	0.8491	128.8400	0.7574	0.7553
BMI	0.8535	0.8388	0.8681	24.8500	0.7525	0.7912
WC	0.8833	0.8704	0.8962	90.0500	0.8276	0.7773
WHR	0.8002	0.7829	0.8175	0.9350	0.7401	0.7153
WHtR	0.8470	0.8320	0.8619	0.5550	0.7690	0.7610

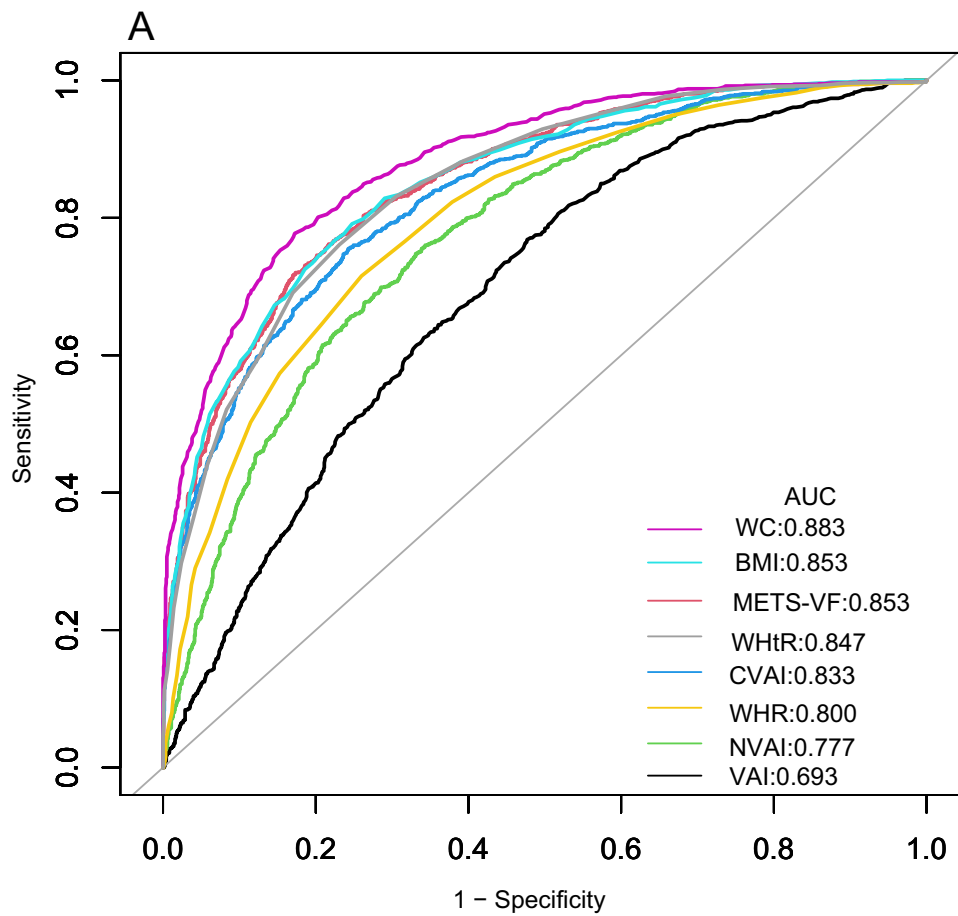


Figure 1 Predictive Ability of Visceral Obesity Related Indices for VO (A).

subcutaneous adipose tissue (SAT) by inhibiting lipolytic activity in the gluteofemoral SAT. Concurrently, estrogen can suppress the activity of lipoprotein lipase and the expression of adipogenic genes, thereby reducing lipid storage in visceral adipose tissue.³¹

Research findings on various visceral obesity-related indices reveal notable differences across populations. In a study conducted in Turkey with participants not suffering from T2DM, a robust relationship was noted between METS-VF and VO, which is considered an accurate indicator of VO. Nonetheless, it did not show a notable benefit compared to WC,

Table 5 Predictive Ability of Visceral Obesity Related Indices for VO in Males

Test	AUC	95% CI low	95% CI upp	Threshold	Specificity	Sensitivity
VAI	0.7186	0.6912	0.7461	2.0350	0.6346	0.7011
METS-VF	0.8563	0.8369	0.8756	6.8987	0.8182	0.7478
NVAI	0.7271	0.7004	0.7538	0.9931	0.7564	0.6052
CVAI	0.8837	0.8665	0.9009	117.3900	0.7839	0.8266
BMI	0.8542	0.8348	0.8735	25.0500	0.7581	0.7909
WC	0.8836	0.8664	0.9007	90.5500	0.8079	0.8106
WHR	0.8072	0.7844	0.8300	0.9350	0.6672	0.7909
WHtR	0.8691	0.8508	0.8874	0.5450	0.7650	0.8106

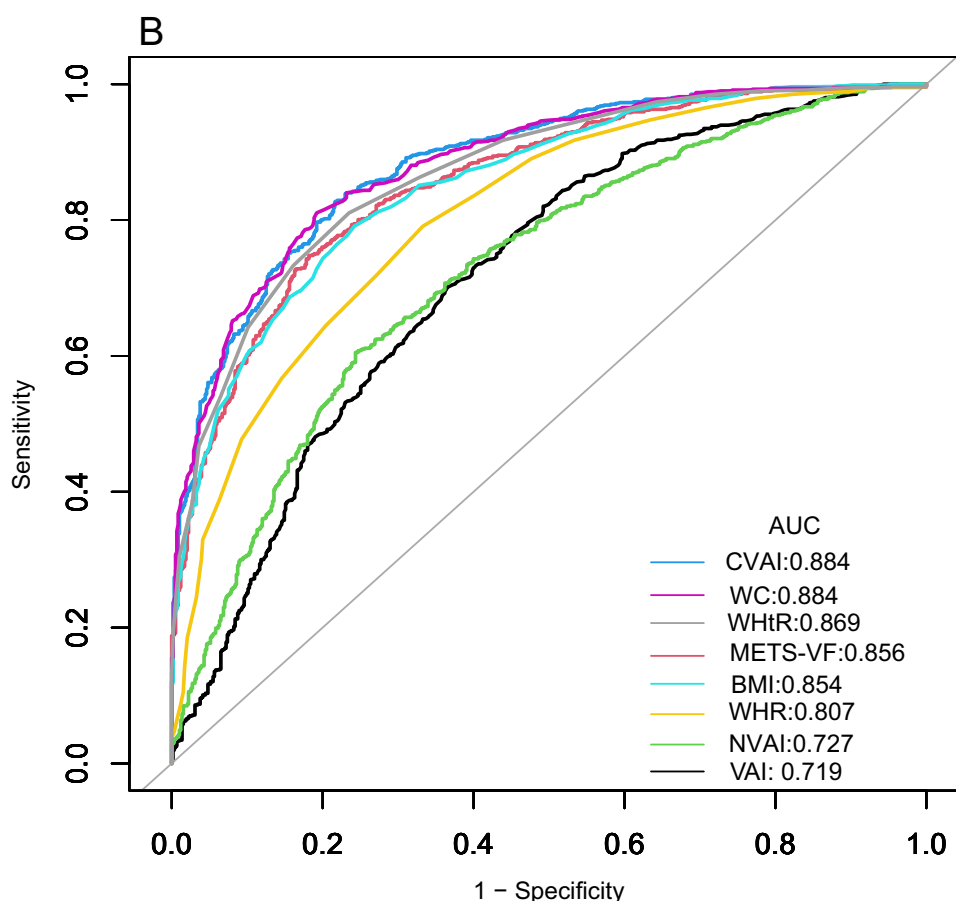


Figure 2 Predictive Ability of Visceral Obesity Related Indices for VO in Males (B).

consistent with our results.³² In contrast, research performed on severely obese individuals in South India demonstrated that METS-VF exhibited a greater AUC than BMI, WC, WHR, and WT, implying its effectiveness as an alternative indicator for VO within this population.³³ This contrasts with the findings of our study, likely due to the selection of metabolically abnormal obese individuals, where traditional measurement indicators may not adequately account for biochemical factors. Furthermore, a study conducted by Ravani et al revealed that, within a group of 40 male pilots from the Brazilian Air Force, the VAI outperformed conventional measures like BMI, WC, WHtR, WHR in predicting

Table 6 Predictive Ability of Visceral Obesity Related Indices for VO in Females

Test	AUC	95% CI low	95% CI upp	Threshold	Specificity	Sensitivity
VAI	0.6931	0.6614	0.7248	2.3450	0.5787	0.7167
METS-VF	0.8445	0.8211	0.8680	6.9228	0.8235	0.7022
NVAI	0.8257	0.8007	0.8506	0.9299	0.7790	0.7119
CVAI	0.8318	0.8068	0.8568	138.7650	0.7886	0.7215
BMI	0.8428	0.8188	0.8669	24.3500	0.7234	0.8063
WC	0.8733	0.8524	0.8943	87.2500	0.7822	0.8015
WHR	0.7689	0.7402	0.7976	0.9050	0.6566	0.7458
WHtR	0.8541	0.8314	0.8767	0.5650	0.7663	0.7869

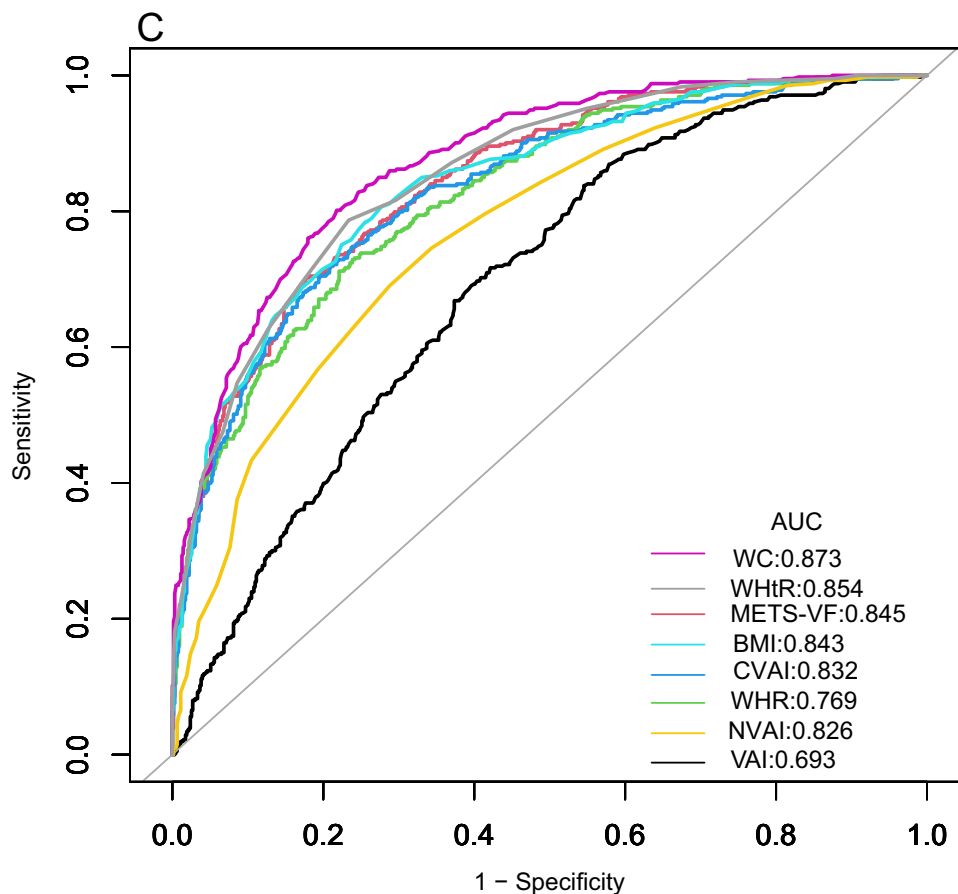


Figure 3 Predictive Ability of Visceral Obesity Related Indices for VO in Females (C).

VO.^{34,35} Similarly, it has been identified that VAI, WC, and WHtR are effective in assessing the increase in VO area associated with dysregulation of glucose and lipid metabolism.³⁵ Nevertheless, our study’s results suggest that VAI does not offer a distinct advantage over traditional measurement indicators and other visceral obesity-related indices. This discrepancy may arise from the fact that VAI was developed based on Caucasian populations, as there are variations in body fat traits across various ethnic groups, Individuals of Asian ancestry appear to have a greater tendency to accumulate VO, potentially affecting the predictive accuracy of VAI within the Chinese demographic.^{36–38}

Table 7 Predictive Ability of Visceral Obesity-Related Indices for VO in Males with Normal WC

Test	AUC	95% CI low	95% CI upp	Threshold	Specificity	Sensitivity
VAI	0.7084	0.6590	0.7579	1.4650	0.5057	0.8047
CVAI	0.7323	0.6850	0.7796	92.4350	0.6150	0.7656
METS-VF	0.6824	0.6313	0.7335	6.5227	0.5262	0.7578
NVAI	0.6108	0.5550	0.6666	0.9921	0.7882	0.4141
BMI	0.7159	0.6686	0.7631	22.9500	0.5103	0.8125
WHR	0.6482	0.5945	0.7020	0.9050	0.6036	0.6328
WHtR	0.6946	0.6456	0.7436	0.5050	0.4738	0.8438

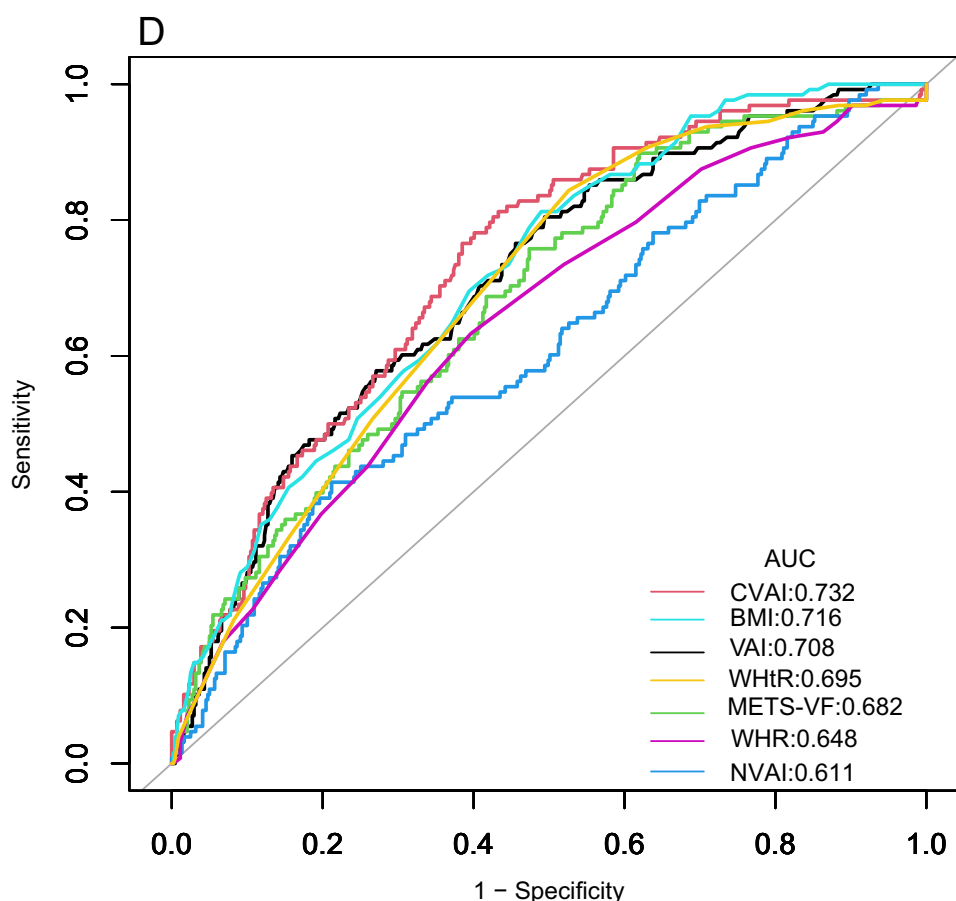


Figure 4 Predictive ability of visceral obesity-related indices for VO in males with normal WC (D).

CVAI, an innovative metric for assessing VO, was created using data from China. Research has indicated that CVAI demonstrates superior predictive capabilities for metabolic syndrome, non-alcoholic fatty liver disease and complications related to diabetes at the microvascular level.^{39–41} Moreover, CVAI demonstrates superior predictive capability for obesity-related metabolic disorders when compared to WC and BMI.⁴² Given that conditions like fatty liver, metabolic syndrome, and complications related to diabetes may indicate insulin resistance, we assessed the effectiveness of CVAI in comparison to other indicators for predicting VO in individuals with T2DM. The findings suggest that CVAI serves as the

Table 8 Predictive Ability of Visceral Obesity-Related Indices for VO in Females with Normal WC

Test	AUC	95% CI low	95% CI upp	Threshold	Specificity	Sensitivity
VAI	0.6469	0.5777	0.7160	1.6950	0.4573	0.8214
CVAI	0.7056	0.6329	0.7784	121.1650	0.7136	0.6250
METS-VF	0.7311	0.6675	0.7947	6.4733	0.6028	0.7857
NVAI	0.7226	0.6557	0.7895	0.7623	0.6120	0.8214
BMI	0.6551	0.5876	0.7226	21.3500	0.3580	0.9107
WHR	0.6383	0.5670	0.7096	0.8650	0.4988	0.7321
WHtR	0.7188	0.6563	0.7812	0.5050	0.4734	0.8750

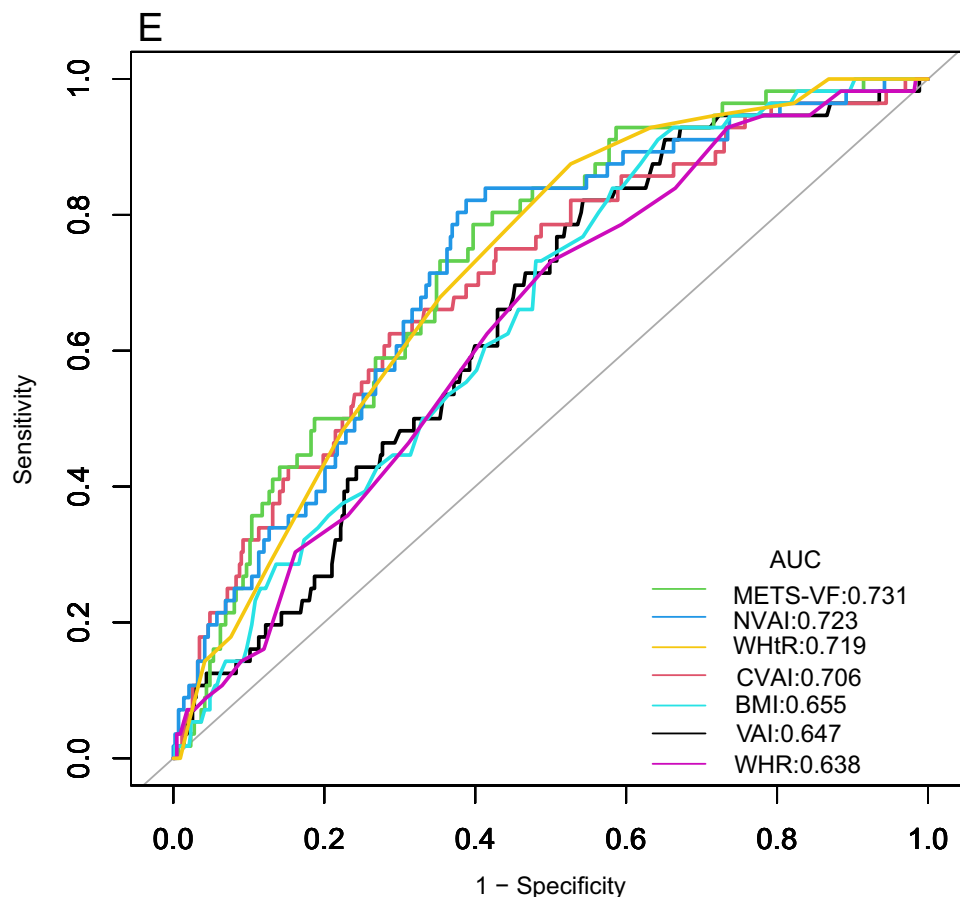


Figure 5 Predictive ability of visceral obesity-related indices for VO in females with normal WC (E).

most reliable measurement for male T2DM patients. Additionally, the recently introduced NVAI, utilizing data from a Korean demographic, has demonstrated a noteworthy relationship with coronary artery calcification, cardiovascular conditions, stroke occurrence and arterial rigidity,⁴³ and demonstrates greater efficacy than WC, VAI, and BMI in forecasting visceral fat accumulation.¹⁸ However, this study suggests that the predictive ability of NVAI for VO in the Chinese T2DM population is inferior to WC and BMI.

The study by Yang et al which included 976 Chinese T2DM patients, indicated that males with a BMI exceeding 24.92 kg/m² and females with a BMI above 24.05 kg/m² have an increased likelihood of developing VO.⁴⁴ In this research, the ideal cutoff value for BMI in males was found to be 25.05 kg/m², whereas for females, it was determined to be 24.35 kg/m², aligning closely with the findings of our study. A separate research project that included 1,539 participants with T2DM in China determined that an ideal BMI is 25 kg/m². The most favorable WC measurements found were 93 cm for males and 90 cm for females.⁴⁵ In this study, the optimal cut-off value for male WC was 90.55 cm, and for female WC was 87.25 cm, showing a slight deviation from the BMI and WC data of that study. This may be because the main subjects of that study were inpatients, and the Japanese diagnostic criteria were used to diagnose VO in T2DM. Research conducted by Lu et al showed that VO may be present in Chinese adults despite having a normal BMI, using diagnostic criteria that exceed the BMI threshold.⁴⁶ Consequently, overall evaluations indicate that the typical BMI threshold values may not precisely represent the degree of obesity among Chinese individuals diagnosed with T2DM. Thus, it is essential to reduce the BMI threshold specifically for individuals with T2DM.

Research indicates that Asians generally possess a lower BMI than Europeans; however, they exhibit a higher overall body fat percentage and larger quantities of VO.⁴⁷ Given that individuals with a normal BMI may still experience VO—an issue associated with dyslipidemia—the indices related to visceral obesity should include lipid parameters.⁴⁶ Hence,

this study conducted a further analysis on individuals with normal WC, revealing that the visceral obesity-related index plays a significant role in assessing the risk of VO among patients with T2DM, both in males and females.

This study is inherently cross-sectional, indicating that it identifies a relationship between measures associated with visceral fat and VO in individuals with T2DM, but does not establish a causal link. Additionally, this study utilized BIA for diagnosing VO. BIA estimates VFA indirectly by measuring the impedance characteristics of human tissue when subjected to weak alternating current. The BIA calculation formula employed in this research included abdominal transverse diameter, abdominal anteroposterior diameter, surface impedance, trunk impedance, residual constant, and constant.⁴⁸ Since abdominal transverse diameter and abdominal anteroposterior diameter are correlated with WC, the predictive effect of WC on VO may be overestimated, highlighting the need for further investigation in future studies. Although the accuracy of BIA in estimating VFA is lower than that of CT and MRI. However, this method showed a strong correlation with CT and MRI and was more cost-effective in assessing VFA and SFA in patients with diabetes.^{11,12} Thirdly, like other observational studies, this research might contain unrecognized or overlooked confounding variables. Lastly, our investigation involved T2DM patients in China, raising doubts about the applicability of the findings to different nations and cultural groups.

Conclusion

This study demonstrates a significant correlation between visceral obesity-related indicators and VO among patients with T2DM. WC has been proven to be the most reliable predictor in the general and female populations, while CVAI has been identified as the best predictor for males. Among individuals with normal WC, CVAI and METS-VF emerge as the most effective predictors for male and female T2DM patients, respectively. Selecting appropriate visceral obesity indicators based on patient characteristics can facilitate early detection of VO in T2DM patients.

Abbreviations

T2DM, Type 2 diabetes mellitus; VO, visceral obesity; VFA, Visceral fat area; SFA, subcutaneous fat area; BMI, Body mass index; WC, Waist circumference; CT, Computed Tomography; MRI, Magnetic Resonance Imaging; BIA, bioelectrical impedance analysis; CVAI, Chinese visceral adiposity index; METS-VF, Metabolic score for VO; NVAI, new visceral adiposity index; VAI, visceral adiposity index; WHR, Waist-to-hip ratio; WHtR, Waist-to-height ratio; Cr, Creatinine; DBP, Diastolic blood pressure; eGFR, estimated Glomerular Filtration Rate; FPG, Fasting plasma glucose; PPF, Post-Prandial Glucose; ALT, Alanine aminotransferase; AST, Aspartate aminotransferase; LDL-C, low-density lipoprotein cholesterol; HDL-C, High density lipoprotein Cholesterol; HbA1c, Glycosylated hemoglobin A1c; LDL-C, Low density lipoprotein Cholesterol; SBP, Systolic blood pressure; UA, Uric acid; TC, Total cholesterol; TG, Triglycerides; WT, weight; HT, height.

Data Sharing Statement

The author responsible for correspondence will supply the original data that underpins the findings of this study upon reasonable request without hesitation.

Ethics Statement

This study was approved by the Medical Ethics Committee of Changde Hospital, Xiangya School of Medicine, Central South University (project number 2020-061-01). Each member of the study signed an informed consent form. Every procedure used in this study complied with the Declaration of Helsinki.

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Disclosure

The authors declare no conflict of interest.

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