

Optimal Cut-Offs of Body Mass Index and Waist Circumference to Identify Obesity in Chinese Type 2 Diabetic Patients

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Qinying Zhao*
Xiangjun Chen*
Jinshan Wu
Lilin Gong
Jinbo Hu
Shumin Yang
Qifu Li
Zhihong Wang

Department of Endocrinology, The First Affiliated Hospital of Chongqing Medical University, Chongqing, People's Republic of China

*These authors contributed equally to this work

Purpose: The prevalence of general obesity (commonly defined by body mass index (BMI) in kg/m^2) and abdominal obesity (commonly assessed by waist circumference (WC)) has increased rapidly in China. The aim of this study was to investigate the diagnostic accuracy of traditional cut-offs for BMI or WC to identify general or abdominal obesity in Chinese type 2 diabetic patients and propose optimal cut-offs.

Patients and Methods: BMI and WC were obtained from 1539 type 2 diabetic patients. Body fat percentage and visceral fat area measured by dual-energy x-ray absorptiometry were set as the gold standard to identify general and abdominal obesity. We assessed the diagnostic power of traditional cut-offs for BMI and WC to define obesity, and analyzed receive operating characteristic (ROC) curves to obtain the optimal cut-offs to identify obesity in Chinese type 2 diabetic patients.

Results: In Chinese type 2 diabetic patients, the optimal BMI was $25 \text{ kg}/\text{m}^2$ with the best trade-off between sensitivity and specificity (men: 74.6% (95% CI: 70.7–78.2%) and 65.1% (95% CI: 59.7–70.3%), AUC 0.78 (95% CI: 0.75–0.81), $p < 0.05$; women: 65.8% (95% CI: 60.3–71.0%) and 80.3% (95% CI: 75.7–84.3%), AUC 0.80 (95% CI: 0.77–0.83), $p < 0.05$) in both genders. The optimal WC was 93 cm in men and 90 cm in women with the best trade-off between sensitivity and specificity (men: 87.2% (95% CI: 84.3–89.8%) and 80.2% (95% CI: 74.9–84.8%), AUC 0.91 (95% CI: 0.88–0.92), $p < 0.05$; women: 81.0% (95% CI: 76.9–84.6%) and 88.7% (95% CI: 83.9–92.4%), AUC 0.92 (95% CI: 0.90–0.94), $p < 0.05$).

Conclusion: For the Chinese patients with type 2 diabetes, the optimal cut-offs for BMI or WC to identify general or abdominal obesity need to be reconsidered.

Keywords: diagnostic test, type 2 diabetes, body mass index, waist circumference, dual-energy X-ray absorptiometry

Introduction

Obesity is associated with the increased risks of type 2 diabetes mellitus (T2DM), cardiovascular diseases (CVDs), cancer and premature mortality.^{1–3} T2DM is one of the most common obesity-associated complications.⁴ Approximately half of the patients with diabetes are overweight or obese.^{5,6} Obesity can not only cause insulin resistance and damage islet function but also lead to metabolic abnormalities,⁷ which can further aggravate the occurrence and development of chronic complications in the diabetes. Therefore, identifying obesity as a disease in a clinical care setting is critical to the management of such T2DM patients.

Correspondence: Zhihong Wang
Department of Endocrinology, The First Affiliated Hospital of Chongqing Medical University, Yuzhong District, Chongqing, People's Republic of China
Tel/Fax +86 023 89011552
Email towzh713@126.com

General obesity and abdominal obesity are the major subtypes of obesity. General obesity, commonly defined by body mass index (BMI) in kg/m^2 , has increased dramatically in China during the past decades.⁸ However, BMI did not represent only fat mass, but also lean mass and bone density. The characteristics of body composition in T2DM, including the increase in total fat mass^{9,10} and the decrease of muscle mass or bone density,^{11,12} which might lead to a normal BMI even with an increase in fat mass. The traditional cut-offs of BMI in general population might underestimate the degree of general obesity in patients with T2DM. Also, current studies have demonstrated that traditional cut-offs of BMI poorly predict diabetes, CVDs and death.^{13–16} Abdominal obesity, commonly assessed by measuring waist circumference (WC), is more strongly associated with the risk of T2DM and all-cause mortality than general obesity.¹⁷ However, in the diabetes, an imbalance in glucose metabolism might severely affect lipid metabolism, leading to a mass of fat accumulation, especially the deposition of abdominal fat.^{9,18,19} Eventually, it resulted in the significant increase in WC than general population. However, it was unclear the cut-offs of WC for general population could correctly judge whether the diabetes were combined with abdominal obesity or not. Of note, the current cut-offs of BMI and WC to diagnose obesity for general population have not been validated for the population with T2DM. Few studies have been performed to determine the optimal cut-offs of BMI and WC for identifying obesity for the patients with T2DM.

Therefore, our study aimed to investigate the diagnostic accuracy of traditional cut-offs for BMI or WC to identify general or abdominal obesity in Chinese type 2 diabetic patients and propose optimal cut-offs. The golden-standard for identifying abdominal obesity is CT and MRI,²⁰ however, they are unsuitable for clinical practices because of high cost and waste time. Advances in dual-energy X-ray absorptiometry (DXA) suggested that this method provides reliable estimates of total body fat^{21–25} and visceral fat.^{26,27} Therefore, body fat percentage (BF%) and visceral fat area (VFA) measured by DXA were set as the gold criteria to identify general and abdominal obesity in our study.

Patients and Methods

Subjects

This study was performed at the Chongqing Diabetes Center, which relies on the First Affiliated Hospital of

Chongqing Medical University, from September 2015 to December 2018. Participants with the following conditions were included: (1) aged from 20 to 85 years; (2) achieved the 1999 World Health Organization (WHO)'s diagnostic criteria for type 2 diabetes mellitus;²⁸ (3) had complete data of body compositions measured by DXA. The exclusion criteria were as follows: (1) secondary obesity: endocrine and metabolic diseases (such as hyperthyroidism, hypothyroidism, Cushing's syndrome, acromegaly, etc.) or drug use (such as exogenous glucocorticoids, antidepressants, teaching psychotropic drugs, etc.); (2) presence of malignant tumor. We screened 1640 individuals including inpatients and outpatients, of whom 101 patients were excluded due to unavailable data or meeting exclusion criteria. Eventually, a total of 1539 subjects (men 870 and women 669) were recruited (Figure 1). Informed consent was obtained from all individual participants included in the study. The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University [2018 Scientific Research Ethics (2018–042)]. This study was conducted in accordance with the Declaration of Helsinki.

Clinical Procedures

The medical history of all patients was documented in detail, such as sex, age and medication including oral hypoglycemic agent (OHA), insulin, antihypertensive drugs and lipid-lowering drugs (LLDs). Anthropometric measurements, including height, weight, WC, systolic blood pressure (SBP), and diastolic blood pressure (DBP), were performed on all participants. Height (m, electronic human scale (HLZ-48, OMRON, Japan)) and weight (kg, electronic human scale (HLZ-48, OMRON, Japan)) were measured by patients standing without shoes and hats, and in light attire. BMI was calculated as weight divided by the square of height. WC was measured at the horizontal plane between the inferior costal margin and the iliac crest on midaxillary line. Glycosylated hemoglobin (HbA1c) was measured by a high-performance liquid chromatography analyzer. Fasting plasma glucose (FPG), 2h plasma glucose (2hPG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), and triglyceride (TG) were measured enzymatically by an automatic analyzer (Model 7080; Hitachi, Tokyo, Japan) with reagents purchased from Leadman Biochemistry Co. Ltd. (Beijing, China). Serum creatinine (SCr) was measured with an automatic biochemical analyzer (Modular DDP, Roche). And the

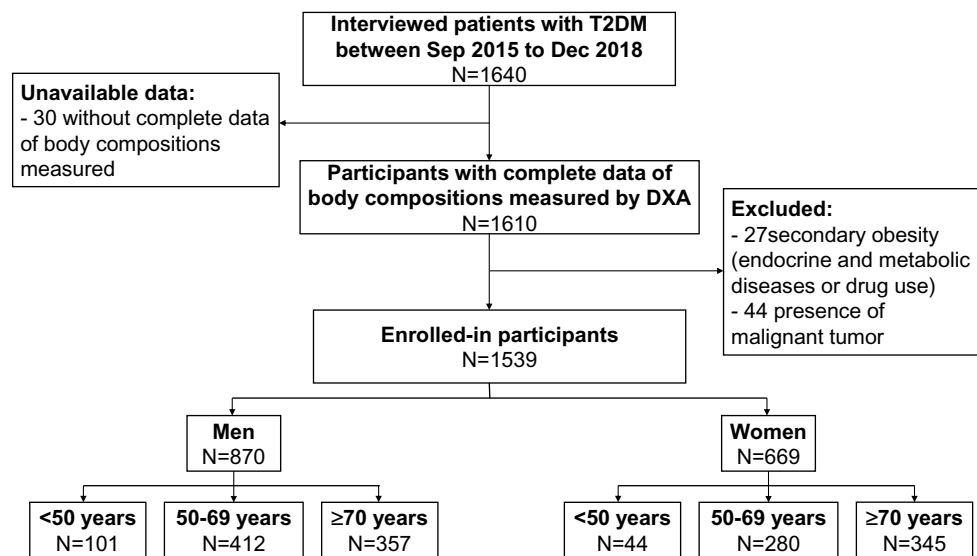


Figure 1 Flow chart of study population in the study.

Abbreviations: T2DM, type 2 diabetes mellitus; Sep, September; Dec, December; DXA, dual-energy X-ray absorptiometry.

estimated glomerular filtration rate (eGFR) was calculated using the Modification of Diet in Renal Disease (MDRD) Study equation (male: $eGFR = 186 \times SCr^{-1.154} \times year^{-0.203}$; female: $eGFR = 186 \times SCr^{-1.154} \times year^{-0.203} \times 0.724$).²⁹

Dual-Energy X-Ray Absorptiometry (DXA)

The DXA (Hologic Discovery QDR[®] Series, Bedford, USA) was used to measure the BF% and VFA by a skilled technician. All standard procedures were performed according to previous studies.^{25,30} The subject was reclined in a supine position and was scanned from head to foot in the standard mode. The scanning range width was fixed at 60 cm, and the scanning time was approximately 20 mins. The Hologic Whole Body DXA Reference Database Software and Hologic Visceral Fat Software were used to estimate the BF% and VFA.^{31,32}

Definition of General and Abdominal Obesity

BF% and VFA measured by DXA were set as the gold criteria to identify general and abdominal obesity in our study. Diagnostic definition of general obesity was BF% $\geq 25\%$ for men or 35% for women,^{33,34} according to the values recommended by the WHO and American Association for Clinical Endocrinology.^{21,22,25} And the cut-off for BF% was also applicable to the Chinese population, which was verified in Chinese population by Weiping Jia et al.³⁵ Diagnostic criterion for abdominal obesity

followed the Examination Committee of Criteria for “Obesity Disease” in Japan 2002 (VFA $\geq 100 \text{ cm}^2$),³⁶ which was same to the standard of NHANES.³⁷

In our population with T2DM, we tested the diagnostic accuracy of the traditional cut-offs for BMI or WC to identify general or abdominal obesity (based on general population) followed by 1993 World Health Organization (WHO) and 2004 Chinese Diabetes Society (CDS) definition, respectively: definition for general obesity in the WHO was $BMI \geq 30 \text{ kg/m}^2$, and definition for abdominal obesity was $WC \geq 102 \text{ cm}$ in men and $\geq 88 \text{ cm}$ in women; Diagnosis of general obesity in the CDS was $BMI \geq 28 \text{ kg/m}^2$, and diagnosis of abdominal obesity was $WC \geq 90 \text{ cm}$ in men and 85 cm in women.³⁸

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Science, version 20.0 (IBM SPSS, Armonk, New York). We divided the subjects into two groups of obesity and non-obesity based on the golden standard. The Kolmogorov–Smirnov test was used to verify the normal distribution of data. For normally distributed variables, data were presented as mean \pm SD and tested by Student’s *t*-test; for non-normally distributed variables, data were presented as the medians (interquartile range) and tested by the Mann–Whitney *U*-test. Categorical variables were reported as frequencies (proportions), and chi-square tests were used for group comparisons. All reported *p* values were two-tailed, and significance level was 0.05 for all the statistical tests. Subjects were also classified according to the

traditional cut-offs for BMI or WC representing general or abdominal obesity. Diagnostic performance was assessed by determining sensitivity, specificity, positive and negative predictive values. We plotted an receiver-operator characteristics (ROC) curves to find the optimal cut-offs of BMI or WC in identifying general or abdominal obesity. The optimal cut-offs of BMI and WC were obtained from the Youden index [maximum (sensitivity + specificity – 1)] by ROC curves. Greater accuracy is selected by a larger Youden index.

Results

Clinical Characteristics of the Participants

The clinical characteristics of our participants with or without obesity were shown in Tables 1 and 2. In 870 men there were 543 (62.4%) defined as general obesity, and 603 (69.3%) diagnosed as abdominal obesity. In 669 women there were 319 (47.7%) diagnosed as general obesity, and 431 (64.4%) defined as abdominal obesity. Both men and women with general obesity had significantly higher age, weight, TG, BF

%, VFA, BMI and WC, while significantly lower HDL-C than those without general obesity ($p < 0.05$). Compared to patients without abdominal obesity in both genders, the levels of weight, DBP, FPG, SCr, TG, BF%, VFA, BMI and WC increased significantly ($p < 0.05$) in subjects with abdominal obesity, while the levels of eGFR and HDL-C decreased significantly ($p < 0.05$). And there were no significant difference in medication for group comparisons (Tables 1 and 2).

Diagnostic Accuracy of the Traditional Cut-Offs of BMI and WC in Chinese Patients with T2DM

The diagnostic accuracy of the traditional cut-offs for BMI to identify general obesity is shown in Table 3, (Supplemental Table 1a and 1b). A BMI of 28 kg/m² (CDS criteria for general obesity) showed a sensitivity of 22.1%, and a specificity of 96.9% for men. However, with this cut-off, the BMI showed a sensitivity of 31.3%, and

Table 1 Clinical Characteristics of the Subjects in Men

Variables	General Obesity (Defined by Body Fat Percentage)			Abdominal Obesity (Defined by Visceral Fat Area)		
	Yes	No	p	Yes	No	p
Men (870)	543 (62.4%)	327 (37.6%)	—	603 (69.3%)	267 (30.7%)	—
Age (years)	63 (55,70)	62 (54,68)	<0.05	63 (55,69)	62 (54,69)	0.178
Height (cm)	168.0 (162.0,171.0)	167.0 (161.0,171.0)	0.261	168.0 (163.0,172.0)	165.0 (160.0,170.0)	<0.05
Weight (kg)	72.2±9.7	63.8±9.9	<0.05	72.4±9.2	61.4±9.5	<0.05
SBP (mmHg)	134 (124,147)	130 (118,144)	<0.05	134 (123,146)	131 (120,145)	0.068
DBP (mmHg)	80 (73,87)	79 (71,85)	0.055	80 (74,88)	77 (70,84)	<0.05
FPG (mmol/L)	7.7 (6.4,10.0)	7.4 (6.0,9.4)	0.084	7.9 (6.4,10.0)	7.2 (5.9,9.3)	<0.05
2hPG (mmol/L)	13.9±5.2	13.1±6.4	0.233	13.7±5.1	13.4±6.6	0.660
HbA1c (%)	8.2 (7.00,10.00)	8.20 (7.00,10.00)	0.983	8.20 (6.90,9.90)	8.50 (6.80,10.90)	0.193
SCr (mmol/L)	77.50 (66.00,92.00)	75.00 (65.93,87.00)	0.061	78.00 (67.00,93.00)	74.00 (65.00,85.00)	<0.05
eGFR (mL/min/1.73/m ²)	89.35±31.44	92.97±25.96	0.072	88.50±30.29	95.75±27.10	<0.05
TG (mmol/L)	1.57 (1.09,2.57)	1.17 (0.81,1.78)	<0.05	1.62 (1.13,2.61)	1.04 (0.73,1.50)	<0.05
TC (mmol/L)	4.23±1.15	4.11±1.10	0.120	4.20±1.14	4.15±1.11	0.548
HDL-C (mmol/L)	1.00 (0.85,1.20)	1.09 (0.87,1.30)	<0.05	0.98 (0.81,1.17)	1.18 (0.97,1.39)	<0.05
LDL-C (mmol/L)	2.54 (1.77,3.20)	2.40 (1.83,3.17)	0.398	2.52 (1.75,3.13)	2.39 (1.94,3.36)	0.591
BF (%)	28.43±2.76	21.97±2.54	<0.05	27.62±3.33	22.37±3.35	<0.05
VFA (cm ²)	143.37±38.15	90.47±29.99	<0.05	144.23±34.26	76.65±19.52	<0.05
WC (cm)	99.9±7.6	90.2±7.7	<0.05	100.0±7.0	87.7±6.9	<0.05
BMI (kg/m ²)	25.7 (23.9,27.6)	23.0 (21.3,24.9)	<0.05	25.7 (24.0,27.6)	22.4 (20.7,23.9)	<0.05
OHA, n (%)	184 (60.7%)	359 (63.3%)	0.452	205 (67.7%)	398 (70.2%)	0.439
Insulin, n (%)	348 (62.4%)	195 (62.5%)	0.969	380 (68.1%)	223 (71.5%)	0.301
Antihypertensive drugs, n (%)	96 (61.1%)	447 (62.7%)	0.717	114 (72.6%)	489 (68.6%)	0.322
LLDs, n (%)	150 (60.5%)	393 (63.2%)	0.458	166 (66.9%)	437 (70.3%)	0.338

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2h plasma glucose; HbA1c, glycosylated hemoglobin; SCr, serum creatinine; eGFR, estimated glomerular filtration rate; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; BF%, body fat percentage; VFA, visceral fat area; BMI, body mass index; WC, waist circumference; OHA, oral hypoglycemic agent; LLDs, lipid-lowering drugs.

Table 2 Clinical Characteristics of the Subjects in Women

	General Obesity (Defined by Body Fat Percentage)			Abdominal Obesity (Defined by Visceral Fat Area)		
	Yes	No	p	Yes	No	p
Women	319 (47.7%)	350 (52.3%)	—	431 (64.4%)	238 (35.6%)	—
Age (years)	67 (61,72)	63 (56,69)	<0.05	66 (60,71)	63 (55,69)	<0.05
Height (cm)	154.0 (151.0,158.0)	155.0 (151.0,159.0)	0.108	155.0 (151.0,159.0)	155.0 (151.0,158.0)	0.099
Weight (kg)	62.0 (57.0,69.0)	55.0 (50.0,60.0)	<0.05	61.0 (56.9,68.0)	51.0 (48.0,56.0)	<0.05
SBP (mmHg)	138±19	135±20	0.073	139±19	133±21	<0.05
DBP (mmHg)	76±11	74±12	0.111	76±11	74±13	<0.05
FPG (mmol/L)	7.5 (6.1,9.5)	7.4 (6.1,9.5)	0.851	7.8 (6.4,9.5)	6.9 (5.8,9.4)	<0.05
2hPG (mmol/L)	12.6 (9.9,15.6)	12.4 (9.4,16.7)	0.986	12.5 (9.9,15.5)	12.5 (9.3,17.0)	0.974
HbA1c(%)	7.9 (6.8,9.7)	7.8 (6.7,9.7)	0.710	7.9 (6.8,9.7)	7.7 (6.7,9.9)	0.570
SCr (mmol/L)	61.00 (52.00,77.00)	59.00 (49.75,71.00)	<0.05	61.00 (52.00,77.00)	58.00 (49.00,67.50)	<0.05
eGFR (mL/min/1.73m ²)	86.51 (63.89,104.07)	89.57 (72.79,108.01)	<0.05	86.23 (64.49,104.34)	91.42 (75.75,112.87)	<0.05
TG (mmol/L)	1.48 (1.11,2.06)	1.39 (0.90,2.09)	<0.05	1.59 (1.18,2.24)	1.11 (0.88,1.69)	<0.05
TC (mmol/L)	4.14 (3.43,5.03)	4.36 (3.70,5.14)	<0.05	4.13 (3.44,4.97)	4.35 (3.74,5.32)	<0.05
HDL-C (mmol/L)	1.21 (0.99,1.43)	1.26 (1.04,1.54)	<0.05	1.17 (0.97,1.37)	1.37 (1.14,1.68)	<0.05
LDL-C (mmol/L)	2.42 (1.82,3.26)	2.57 (1.96,3.28)	0.108	2.41 (1.84,3.19)	2.63(2.07,3.42)	<0.05
BF (%)	38.29±2.47	31.13±3.17	<0.05	36.53±3.55	30.95±3.99	<0.05
VFA (cm ²)	144.49±40.72	94.76±35.35	<0.05	143.67±34.34	72.85±20.53	<0.05
WC (cm)	97.8±8.8	88.4±8.2	<0.05	97.7±7.8	84.2±5.9	<0.05
BMI (kg/m ²)	26.6±3.4	22.9±2.9	<0.05	26.2±3.2	21.8±2.5	<0.05
OHA, n (%)	120 (51.9%)	199 (45.4%)	0.109	158 (68.4%)	273 (62.3%)	0.119
Insulin, n (%)	208 (48.3%)	111 (46.6%)	0.688	280 (65.0%)	151 (63.4%)	0.694
Antihypertensive drugs, n (%)	56 (45.9%)	263 (48.1%)	0.663	82 (67.2%)	349 (63.8%)	0.477
LLDs, n (%)	106 (50.0%)	213 (46.6%)	0.414	142 (67.0%)	289 (63.2%)	0.347

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2h plasma glucose; HbA1c, glycosylated hemoglobin; SCr, serum creatinine; eGFR, estimated glomerular filtration rate; TG, triglyceride; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; BF%, body fat percentage; VFA, visceral fat area; BMI, body mass index; WC, waist circumference; OHA, oral hypoglycemic agent; LLDs, lipid-lowering drugs.

Table 3 Diagnostic Performance for BMI Using Cut-Offs of ≥ 28 kg/m² (the CDS Standard) and ≥ 30 kg/m² (the WHO Definition) by Age Group and Sex

	BMI ≥ 28 kg/m ²					BMI ≥ 30 kg/m ²				
	Sensitivity	Specificity	PPV	NPV	Accuracy	Sensitivity	Specificity	PPV	NPV	Accuracy
Men										
Total	22.1	96.9	92.3	42.8	50.2	8.5	99.4	95.8	39.5	42.6
<50 years	27.6	100.0	100.0	50.6	61.4	12.1	100.0	100.0	45.7	49.5
50–69 years	24.3	96.0	90.2	45.8	53.0	7.9	99.6	96.4	41.9	44.5
≥ 70 years	14.6	98.2	95.5	31.3	38.3	8.3	98.2	92.3	29.8	33.8
Women										
Total	31.3	96.6	89.3	60.7	65.5	14.7	99.1	94.0	56.1	58.9
<50 years	42.9	91.9	50.0	89.5	84.1	14.3	97.3	50.0	85.7	84.1
50–69 years	33.5	97.0	90.7	62.7	67.5	17.2	100.0	100.0	58.2	61.6
≥ 70 years	26.6	97.5	93.5	49.0	56.4	10.1	97.5	84.6	44.0	46.8

Note: All sensitivity, specificity, accuracy and predictive values represent percentages.

Abbreviations: BMI, body mass index; CDS, Chinese Diabetes Society; WHO, World Health Organization; PPV, positive predictive value; NPV, negative predictive value.

a specificity of 96.6% for women. As the cut-off for BMI increased from 28 to 30 kg/m² (WHO criteria for general obesity), the sensitivity dropped and the specificity increased in both genders. In this study, subjects were also stratified into subgroups by the age <50 years, 50–69 years and ≥ 70 years. Using a BMI of 28 kg/m² or

30 kg/m² as the cut-off value, the highest rate of missed diagnosis was found in patients older than 70 years old in both genders.

A WC of 90 cm in men and 85 cm in women (CDS criteria for abdominal obesity) had a high sensitivity (men: 95.0%; women: 97.4%) and a moderately low specificity (men: 63.7%; women: 58.4%) to identify abdominal obesity. When the cut-off for WC was set according to the WHO standard (WC ≥102 cm in men and 88 cm in women), the sensitivity was decreased to 37.0% in men and 90.3% in women, and the specificity was increased to 98.5% in men and 76.5% in women. The Chinese patients with T2DM older than 70 years old had higher diagnostic accuracies of WC in both genders either by the CDS or the WHO standard (Table 4, Supplemental Table 1c and 1d).

The Optimal Cut-Offs of BMI and WC for General and Abdominal Obesity

Using BMI to confirm general obesity, the ROC curve analysis showed that the AUC of the BMI was 0.78 (95% confidence interval (CI), 0.75–0.81) for men (Figure 2A) and 0.80 (95% CI, 0.77–0.83) for women (Figure 2C). As shown in Table 5 and Supplemental Table 2a, the ideal BMI was 24.0 kg/m² for men (sensitivity: 74.6% (95% CI: 70.7–78.2%); specificity: 65.1% (95% CI: 59.7–70.3%)) and 25.1 kg/m² for women (sensitivity: 65.8% (95% CI: 60.3–71.0%); specificity: 80.3% (95% CI: 75.7–84.3%)) with the best trade-off between sensitivity and specificity, which was round to 25 kg/m² in both genders. For the older patients (more than 70 years

old), the optimal BMI cut-off needed to be lower than younger patients (<50 years old and 50–69 years old).

Using WC to confirm abdominal obesity, the ROC curve analysis showed that the AUC of the WC was 0.91 (95% CI, 0.88–0.92) for men (Figure 2B) and 0.92 (95% CI, 0.90–0.94) for women (Figure 2D). As shown in Table 6 and Supplemental Table 2b, the optimal WC was 93 cm for men and 90 cm for women with the best trade-off between sensitivity (men: 87.2% (95% CI: 84.3–89.8%); women: 81.0% (95% CI: 76.9–84.6%)) and specificity (men: 80.2% (95% CI: 74.9–84.8%); women: 88.7% (95% CI: 83.9–92.4%)). In age subgroup, the optimal cut-off for WC in younger patients (<50 years old and 50–69 years old) was similar to that in older patients (≥70 years old).

Discussion

Our study suggested that the traditional cut-offs of BMI and WC underestimate the degree of obesity in Chinese patients with T2DM. In order to strengthen the diagnosis and management of obesity in Chinese patients with T2DM, we proposed the optimal cut-offs of BMI (25 kg/m²) or WC (men: 93cm; women: 90cm) for defining general or abdominal obesity through ROC curves analysis.

Obesity, and especially abdominal obesity, is considered one of the most important risk factors for T2DM³⁹ and is also consistently associated with marked reductions in insulin sensitivity.⁴⁰ Therefore, it is crucial to accurately identify obesity in patients with T2DM. Nowadays, patients with T2DM are usually diagnosed as obese followed the criteria applicable to the general population. But

Table 4 Diagnostic Performance for WC Using Cut-Offs of ≥90 cm in Men or 85 cm in Women (the CDS Standard) and ≥102 cm in Men or 88 cm in Women (the WHO Definition) by Age Group and Sex

	WC≥90 cm in Men or 85 cm in Women					WC≥102 cm in Men or 88 cm in Women				
	Sensitivity	Specificity	PPV	NPV	Accuracy	Sensitivity	Specificity	PPV	NPV	Accuracy
Men										
Total	95.0	63.7	85.5	85.0	85.4	37.0	98.5	98.2	40.9	55.9
<50 years	98.4	63.2	81.6	96.0	85.1	33.3	97.4	95.5	46.8	57.4
50–69 years	93.9	64.0	85.4	82.4	84.6	35.4	98.3	97.9	40.4	54.8
≥70 years	96.6	63.0	87.7	87.2	87.6	42.9	100.0	100.0	39.1	58.2
Women										
Total	97.4	58.4	80.9	92.7	83.6	90.3	76.5	87.4	81.2	85.4
<50 years	94.4	61.5	63.0	94.1	75.0	94.4	69.2	68.0	94.7	79.5
50–69 years	97.9	59.0	81.1	93.9	84.0	89.7	77.6	87.8	80.7	85.4
≥70 years	97.0	55.4	83.7	88.6	84.6	90.9	76.8	90.2	78.2	86.7

Note: All sensitivity, specificity, accuracy and predictive values represent percentages.

Abbreviations: WC, waist circumference; CDS, Chinese Diabetes Society; WHO, World Health Organization; PPV, positive predictive value; NPV, negative predictive value.

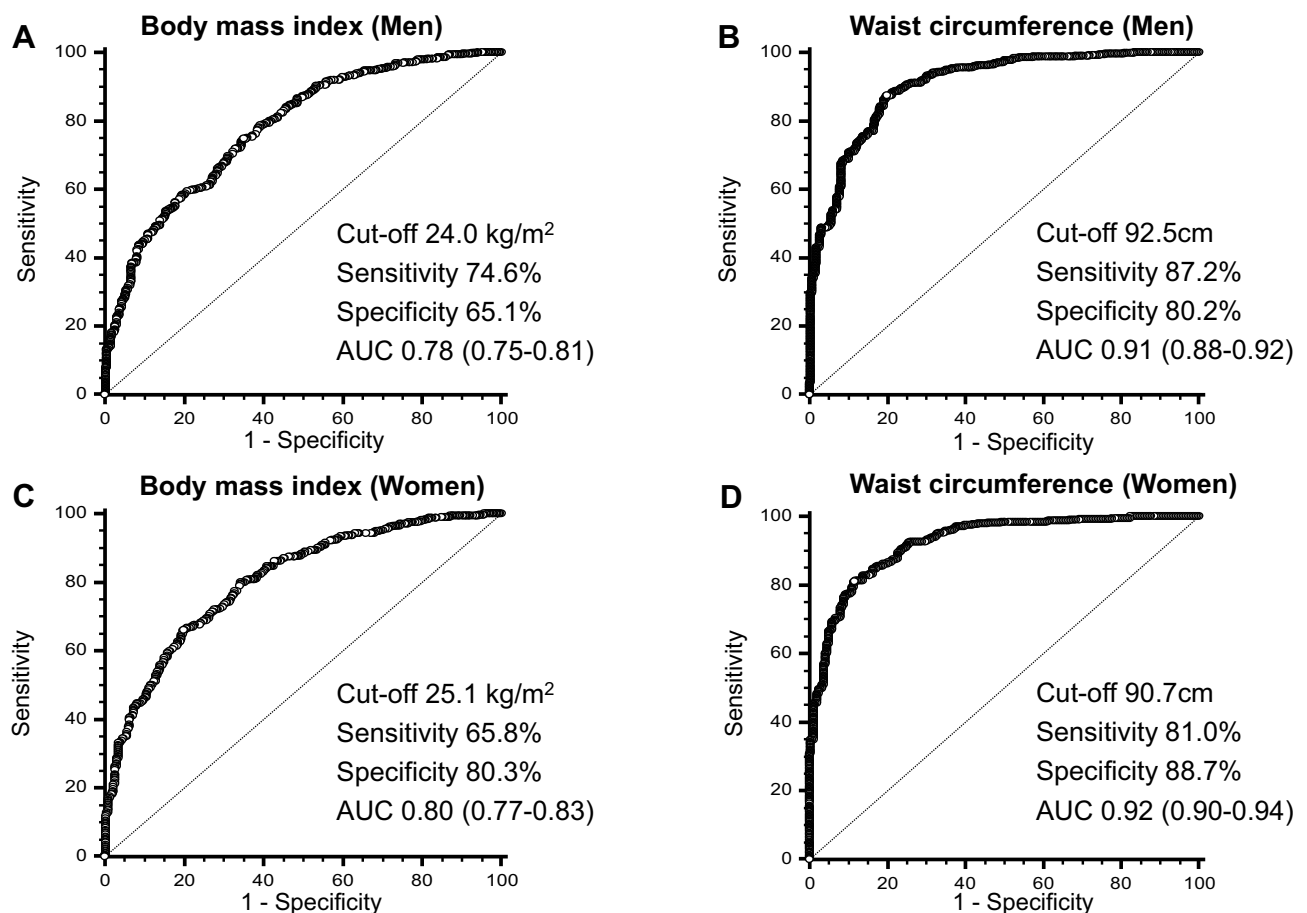


Figure 2 Receiver-operator characteristics (ROC) curves of body mass index (BMI) and waist circumference (WC) to detect body fat percentage and visceral fat area by sex. ROC curves of BMI for all subjects included in this analysis to detect body fat percentage by sex.

Notes: (A) Men and (C) women; ROC curves of WC for all subjects included in this analysis to detect visceral fat area by sex. (B) Men and (D) women.

Abbreviation: AUC, area under curves.

the current cut-offs of BMI and WC to diagnose obesity for general population have not been validated for the population with T2DM. Therefore, the primary objective

of our study is to investigate the diagnostic accuracy of the BMI or WC cut-offs (CDS and WHO standard) for identifying general or abdominal obesity in patients with T2DM.

Table 5 Sensitivity, Specificity, AUC and Youden Index of BMI to Identify BF% in Association with General Obesity

	Cut-Off (kg/m ²)	Sensitivity	Specificity	AUC	Youden Index	p
Men						
Total	24.0	74.6(95% CI:70.7–78.2)	65.1(95% CI:59.7–70.3)	0.78(95% CI:0.75–0.81)	0.40	<0.05
<50 years	25.5	67.2(95% CI:53.7–79.0)	83.7(95% CI:69.3–93.2)	0.82(95% CI:0.72–0.88)	0.51	<0.05
50–69 years	24.2	74.1(95% CI:68.2–79.4)	65.5(95% CI:57.7–72.7)	0.78(95% CI:0.73–0.81)	0.40	<0.05
≥70 years	24.0	71.5(95% CI:63.4–78.7)	73.7(95% CI:60.3–84.5)	0.79(95% CI 0.74–0.83)	0.46	<0.05
Women						
Total	25.1	65.8(95% CI:60.3–71.0)	80.3(95% CI:75.7–84.3)	0.80(95% CI:0.77–0.83)	0.46	<0.05
<50 years	23.9	100(95% CI:59.0–100)	62.2(95% CI:44.8–77.5)	0.85(95% CI:0.71–0.94)	0.62	<0.05
50–69 years	25.1	65.5(95% CI:56.1–74.1)	81.7(95% CI:74.9–87.3)	0.79(95% CI:0.74–0.84)	0.47	<0.05
≥70 years	23.1	89.3(95% CI:84.1–93.2)	61.1(95% CI:52.8–68.9)	0.81(95% CI 0.77–0.85)	0.50	<0.05

Notes: Significant difference ($p < 0.05$) of the AUC for BMI was compared with the gold criteria. All sensitivity and specificity represent percentages.

Abbreviations: BMI, body mass index; BF%, body fat percentage; AUC, area under curves; 95% CI, 95% confidence interval.

Table 6 Sensitivity, Specificity, AUC and Youden Index of WC to Identify VFA in Association with Abdominal Obesity

	Cut-Off(cm)	Sensitivity	Specificity	AUC	Youden Index	p
Men						
Total	92.5	87.2(95% CI:84.3–89.8)	80.2(95% CI:74.9–84.8)	0.91 (95% CI:0.88–0.92)	0.67	<0.05
<50 years	92.2	93.7(95% CI:84.5–98.2)	79.0(95% CI:62.7–90.4)	0.90 (95% CI:0.83–0.96)	0.73	<0.05
50–69 years	92.7	84.8(95% CI:80.1–88.7)	80.5(95% CI:72.4–87.1)	0.89 (95% CI:0.86–0.92)	0.65	<0.05
≥70 years	92.5	89.1(95% CI:82.9–93.6)	77.8(95% CI:64.4–88.0)	0.92 (95% CI:0.89–0.95)	0.69	<0.05
Women						
Total	90.7	81.0(95% CI:76.9–84.6)	88.7(95% CI:83.9–92.4)	0.92 (95% CI:0.90–0.94)	0.70	<0.05
<50 years	90.7	94.4(95% CI:72.7–99.9)	84.6(95% CI:65.1–95.6)	0.90 (95% CI:0.77–0.97)	0.79	<0.05
50–69 years	89.4	86.3(95% CI:80.0–91.2)	81.5(95% CI:73.4–88.0)	0.91 (95% CI:0.87–0.94)	0.68	<0.05
≥70 years	90.3	82.5(95% CI:77.3–87.0)	92.5(95% CI:85.1–96.9)	0.94 (95% CI:0.91–0.97)	0.75	<0.05

Notes: Significant difference ($p < 0.05$) of the AUC for WC was compared with the gold criteria. All sensitivity and specificity represent percentages.

Abbreviations: WC, waist circumference; VFA, visceral fat area; AUC, area under curves; 95% CI, 95% confidence interval.

We found that if we chose the BMI cut-off recommended by CDS or WHO criterion, respectively, the BMI showed a low sensitivity (men: 22.1%, women: 31.3% followed CDS criterion; men: 8.3%, women: 14.7% followed WHO criterion). There were some obese patients to be missed. The phenomenon might partially be caused by the difference in body composition between diabetes and general population. For T2DM patients, the decreased mass of muscle and bone might lead to weight loss,¹¹ resulting in their BMI to some extent lower. Therefore, the BMI cut-off needed to be lowered for T2DM patients. Additionally, in the age subgroup analysis, our analysis suggested that the diagnostic power of BMI decreased in both genders with increased age. It could be explained by the changes observed in body composition occurring with aging, including the gradual increase in fat mass, the decrease in muscle mass and quality or sarcopenia.²⁵ If we chose the WC cut-off recommended by CDS criterion, a high sensitivity (men: 95.0%; women: 97.4%) and a relative low specificity (men: 63.7%; women: 58.4%) were observed. On contrary, followed the WC cut-off by WHO criterion, a lower sensitivity (men: 37.0%; women: 90.3%) and a higher specificity (men: 98.5%; women: 76.5%) were observed. Additionally, in the age subgroup analysis, the older patients (≥ 70 years old) had higher diagnostic accuracies of WC to identify abdominal obesity than the younger ones (<50 years old and 50–69 years old) in both genders. It could be explained by the increase of visceral fat with aging.⁴¹ And this phenomenon might be caused by the reduced secretion of sex hormones and growth hormones, and the decrease of basal metabolism.^{41,42} In conclusion, the traditional cut-offs for

BMI and WC could not accurately identify obesity for patients with T2DM.

There were very few studies studying the optimal cut-offs of BMI and WC to identify general and abdominal obesity for the patients with T2DM. In our study, the best cut-offs of BMI and WC were selected by the largest Youden index by ROC curves. The optimal cut-off of BMI was round to 25 kg/m² with the best trade-off between sensitivity and specificity (men: 74.6% and 65.1%, AUC 0.78; women: 65.8% and 80.3%, AUC 0.80) in both sexes. And the optimal cut-off of WC was 93 cm in men and 90 cm in women with the best trade-off between sensitivity and specificity (men: 87.2% and 80.2%, AUC 0.91; women: 81.0% and 88.7%, AUC 0.92). In the age subgroup analysis, the optimal BMI mostly decreased in both genders with increased age. Younger Chinese patients with T2DM (<50 years old and 50–69 years old) had higher BMI cut-off than older Chinese patients with T2DM (age ≥ 70 group). While the optimal cut-off of WC in younger patients (<50 years old and 50–69 years old) was similar to that in older patients (≥ 70 years old). It suggested age should be taken into consideration when using BMI and WC to indicate obesity.

Our study has the following strengths. First, as far as we know, this study was the first to propose the BMI and WC cut-offs for the diagnosis of obesity in Chinese patients with T2DM. Our work is expected to find more obese patients from T2DM population; Second, the population studied with a relatively large sample size (1539 patients had detailed data of DXA), which ranged from 20 to 85 years, were relatively comprehensive. Several

limitations should be mentioned. First, BF% and VFA measured by DXA were set as the gold criteria to identify general and abdominal obesity in our study. Although MRI and CT provide the most accurate measurement of abdominal obesity, the DXA method for measuring VFA has been validated against direct measures using CT²⁶ and MRI²⁷ (with R^2 ranging between 0.82 and 0.96). DXA is also used to quantitate the total body fat, and body fat percentage (BF%) is recommended to diagnose general obesity which has been validated in previous studies.^{21–25} Besides, subjects in our study were selected from a single center. Considering the difference of lifestyles and living standards among the regions in China, our results may not represent the whole population, so the results needed to be verified by a larger sample size from a multicenter population.

Conclusion

In summary, the BMI of 25 kg/m² in both genders may be the optimal cut-off to diagnose general obesity, and the appropriate cut-off of WC for identifying abdominal obesity is 93 cm for men and 90 cm for women for Chinese type 2 diabetic patients. The diagnostic power of the optimal cut-offs for BMI and WC were superior to that of traditional cut-offs in both genders. In Chinese patients with T2DM, the optimal cut-offs of BMI and WC may improve the early identification and intervention of general and abdominal obesity for reducing obesity-associated complications.

Data Sharing Statement

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Informed Consent

The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University [2018 Scientific Research Ethics (2018-042)]. Written informed consent was obtained from all individual participants included in the study. This study was conducted in accordance with the Declaration of Helsinki. All authors and individual participants provided consent for publication.

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Author Contributions

The first draft of the manuscript was written by Qinying Zhao and Xiangjun Chen. All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in revising the article for important intellectual content; gave final approval of the version to be published; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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