Original Article

The adiposity indicators in relation to diabetes among adults in China: a cross-sectional study from China Health and Nutrition Survey

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Background: Diabetes is a metabolic disease which has been confirmed to be involved with abnormal or excessive body fat accumulation. There is still a lack of nationwide research in China to discuss the relationship between adiposity indicators included body mass index (BMI), waist circumference (WC), visceral adiposity index, waist-height ratio, waist-to-hip ratio (WHR) and diabetes. The question of which one is the best indicator of obesity to predict diabetes in China remains to be unclear.

Methods: Data were collected from the China Health and Nutrition Survey (CHNS) in 2009, including 7,930 participants aged over 18 years old for cross-sectional analysis. Information about height, weight, WC, hip circumference, smoking status, alcohol consumption, physical activity, energy intake and blood samples were analyzed. Binary logistic regression models were used to explore the association of WC, BMI, WHR, waist-to-height ration (WHtR) and visceral adipose index (VAI) with the prevalence of diabetes in the 2009 CHNS respectively. Predictive potential of five adiposity indicators was validated by the area under the receiver operator characteristic curve (AUROC). The optimal cut-off points were determined by Youden's index, which was used to estimate the performance of adiposity indicators.

Results: The study shows patients in the highest quartile were more likely to have diabetes than those in the lowest quartile of WC (OR: 4.237, 95% CI: 3.265–5.499), BMI (OR: 3.312, 95% CI: 2.601–4.218), WHR (OR: 3.199, 95% CI: 2.493–4.104), WHtR (OR: 3.760, 95% CI: 2.891–4.890), VAI (OR: 4.347, 95% CI: 3.411–5.541). The area under the receiver operator characteristic curve of WC, BMI, WHR, WHtR and VAI for diabetes was 0.700, 0.663, 0.668, and 0.697 and 0.694, respectively. The optimal cut-offs regarding diabetes in Chinese are WHtR ≥0.520 for men and VAI ≥1.878 for women.

Conclusions: Our findings indicate that WC, WHtR, BMI, WHR and VAI are all independent risk factors for diabetes among Chinese adults. WHtR is the most accurate indicator for diabetes in men, while VAI for women.

Keywords: Diabetes; abdominal obesity; adiposity indicators; the China Health and Nutrition Survey (CHNS)

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Introduction

Diabetes is a leading cause of mortality, morbidity, and health-system costs in the world, which is a metabolic disease, involving abnormally elevated blood glucose levels (1-3). The mechanism of diabetes may include autoimmune β-cell destruction, insulin resistance and diseases of the exocrine pancreas (4). Over the course of the past 40 years, number of people with diabetes in the adult population has increased from 108 million to 415 million which was estimated by the World Health Organization (5). What's worse, almost half of all people living with diabetes did not recognize that they have been attacked by this disease yet. Particularly, elevated blood glucose was reported to be in relation to macrovascular and microvascular complications, which may bring about several cardiovascular diseases (CVDs) and diabetic kidney disease respectively. Consequently, diabetes brings the world a heavy burden of economic and public health on account of its prevalence, death and healthcare expenditure.

It has been confirmed that obesity, a kind of abnormal or excessive body fat accumulation, increases the risk of many chronic diseases, such as type 2 diabetes, nonalcoholic fatty liver disease, coronary heart disease, asthma and certain types of cancer (6-9). The conventional view is that nutritional excess attenuates insulin's metabolic actions in the liver, skeletal muscle and adipose tissue, and in other words, overnutrition may bring peripheral tissue resistance to insulin's actions, with that comes hyperinsulinemia which leads to diabetes. However, a recent study has found that hyperinsulinemia in prone individuals might drive insulin resistance (10). In brief, the association of obesity and diabetes has been confirmed in considerable paper reports (11-14).

There are several convenient, economical and safe adiposity indicators to gauge obesity, such as body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR), visceral adiposity index (VAI). Though BMI is the most disposable one to measure overweight and obesity, it underestimates the excess of body fat (15). People can measure body shape better with WHtR. Furthermore, some researchers claim that WHtR is a better predictor of CVD risk factors in children than BMI (16). A systematic review claimed that WHtR is a predictor of diabetes independent of BMI (17). Similarly, a cohort study in Japan also illustrated that overweight individuals with abdominal obesity have increased risk of diabetes than that in overweight individuals without abdominal obesity, and abdominal obesity was defined as waist-to-height ratio ≥0.5 (18). Researchers in Jordan hold the idea that WHtR is better than other anthropometric measures in predicting diabetes. Beyond that, they also recommend a cut-off value of 0.6 for women to predict diabetes among Jordanian, which is different from man (19). As for other indicators, WHR was confirmed to be associated with increased risk of type 2 diabetes and coronary heart disease (20). Combination of BMI and WC was better to predict diabetes than BMI (21). Although visceral adiposity index (VAI) requires more complicated procedures and costs more, it is a relatively accurate method to determine visceral adipose. Even though there have been some studies to discuss the relationship between adiposity indicators and diabetes, it may vary among different genders and regions. There is still a lack of nationwide research in China to discuss the relationship between adiposity indicators included BMI, WC, WHR, WHtR, VAI and diabetes. The question of which one is the best indicator of obesity to predict diabetes in China remains to be unclear. This study is designed to compare the association between the indicators and diabetes in a cross-sectional study from the 2009 phase of the China Health and Nutrition Survey (CHNS). We present the following article in accordance with the STARD reporting checklist (available at https://apm.amegroups.com/article/view/10.21037/apm-21-3072/rc).

Methods

Study design and participants

All data used in this study are from the CHNS, an ongoing, longitudinal, population-based cohort study of ten waves [1989–2015], whose purpose is to investigate how the social and economic transformation of Chinese society is affecting the health and nutritional status of its population (22,23). An international team of researchers uses a multistage, random cluster process to draw the samples surveyed in randomly selected four counties, a provincial capital and a lower income city within each province. The survey covers nine provinces including Heilongjiang, Liaoning, Shandong, Henan, Jiangsu, Hubei, Hunan, Guizhou, Guangxi that vary substantially in geography, economic development, public resources, and health indicators. And then, people select twenty households distributing in urban and suburban neighborhoods within the cities and villages and townships within the counties, where individuals live. In thus, the sample is very representative in the population distribution from north to south of China. Given the fact that diagnosis of diabetes needs blood samples, this paper used the cross-sectional data collected from 2009 CHNS (blood samples were collected in 2009 and 2015 while only data in 2009 are available now) (24). We recruited 12,178 participants over 18 years old to complete some questionnaires about their lifestyle such as dietary habit, physical activity, alcohol consumption and smoking status. All participants were also encouraged to complete blood collection and physical measurements. In this study, we did some research on adults aged 18 years and over. Then, we excluded 192 participants without related data about FBG, HbA1C, diabetes history and use of antidiabetic drugs, 149 of pregnant or cancer, 968 without data about smoking, alcohol consumption, hypertension, WC, BMI, WHtR, WHR, physical activity, energy intake and educational level, 2,465 without measuring uric acid (UA), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), alanine aminotransferase (ALT), total cholesterol (TC) and triglyceride (TG), leaving 4,125 female adults and 3,805 male adults participating in the baseline analysis. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Physical examination and serum biochemical parameters

Based on the World Health Organization standard, researchers require participants to weigh themselves and measure their height without heavy clothes and shoes in a comfortable zoom (25). A Seca tape (Seca North America, Chino, CA, USA) was used to measure participants' WC. BMI was defined as the weight in kilograms divided by the square of the height in meters, while WHtR was defined as the WC in centimeters divided by the height in centimeters. Similarly, WHR was defined as the WC in centimeters divided by the hip circumference. The formula used to calculate the value of VAI is different in men and women (26).

For men,

$$\left(\frac{wc}{39.68+1.88\times BMI}\right)\times\left(\frac{TG}{1.03}\right)\times\left(\frac{1.31}{HDL}\right) \quad [1]$$

For women,

$$\left(\frac{wc}{36.58+1.89\times BMI}\right)\times\left(\frac{TG}{0.81}\right)\times\left(\frac{1.52}{HDL}\right) \quad [2]$$

Blood pressure (BP) was measured by the use of mercury sphygmomanometer in a comfortable zoom, where participants needed to sit for at least 5 minutes. A total of three BP measurements were taken 1 minute apart and averaged for records. Hypertension was defined when systolic BP (SBP) was greater than or equal 140 mmHg, or diastolic BP (DBP) was greater than or equal 90 mmHg, and (or) antihypertensive drugs were taken within two weeks. After at least 8 h of overnight fasting, blood collections were completed by venipuncture and tested at once for glucose within local laboratories of each site. Testing of glycosylated hemoglobin (HbA1c) needs to be completed only in one of the provincial laboratories, while testing of other biochemical and immunological detection is to be completed in China-Japan Friendship Hospital, Ministry of Health laboratory [International Standards Organization (ISO) medical laboratory accreditation certificate 15189:2007] (27). Hitachi 7600 automated analyzer (Hitachi Inc., Tokyo, Japan) was used to deal with blood samples above. According to the 2020 American Diabetes Association (ADA) criteria, those people who were diagnosed as diabetes may have used hypoglycemic drugs, or their fasting glucose levels ≥7.0 mmol/L or HbA1c ≥6.5% (4).

Other covariates

Data about physical activity in the past 7 days, which includes domestic, occupational, transportation and leisure activity, was collected by questionnaire (28). For example, participants were asked about their transportation to and from work or school, including walk, bicycle, bus or car. We also provide some specific choices, such as martial arts, badminton or TV, for participants for physical activities and sedentary activities. Thus, researchers estimate the level of physical activity with the multiplication of time spent in each activity and metabolic equivalent for that activity based on the Compendium of Physical Activities (29). Three days' worth of detailed household food consumption information is collected, a condition in which researchers can easily obtain an average per day amount of the energy intake. Other covariates such as age, gender, Han nationality (yes or no), educational level (illiteracy, primary school, junior high school, high school or above), current smoker (yes or no), alcohol consumption during the past year (yes or no), and hypertension (yes or no) were self-reported and recorded by interviewers using structured questionnaire.

Statistical analysis

For continuous variables, the descriptive analysis is determined according to whether the data obeys normal distribution. Values are expressed as means ± SDs or medians (IQRs) for continuous variables and numbers (percentages, %) for categorical variables. Characteristics of subjects with or without diabetes were compared using two-sample *t*-test or the Mann-Whitney U test for continuous variables and a χ^2 test for categorical variables. The number of populations are divided into four equal parts by the value of WC, WHtR, BMI, WHR or VAI. Binary logistic regression models were constructed to explore the association of adiposity indicators with diabetes in the 2009 CHNS. Model 1 was unadjusted; Model 2 was adjusted for current smoker (yes or no), age, education (Illiteracy, primary school, junior high school, high school or above), Han nationality (yes or no); Model 3 was adjusted for all variables in Model 2 as well as physical activity (MET-h/week), energy intake(kcal/d), hypertension (yes or no) and TC. Predictive potential of five adiposity indicators were validated by the area under the receiver operator characteristic curve (AUROC). The optimal cut-off points were determined by Youden's index, which could predict prevalence of diabetes. A data analysis software, Statistical Package for Social Sciences Version 20.0, was used to carry out all statistical tests. A two-sided P<0.05 was considered to be of statistical significance.

Results

Characteristics of subjects from the 2009 CHNS

In our study, altogether 7,930 participants were included in cross-sectional analysis from 2009 CHNS. *Tables 1,2* demonstrated populational characteristics in males and females respectively. The mean age of male participants was 50.4±15.1 years, while the mean age of females was 50.2±14.5 years. Among 3,805 male subjects from the 2009 CHNS, there is no significant differences in alcohol consumption, educational levels, value of LDL-C (P>0.05) according to occurrence of diabetes. Males with diabetes were more likely to be old, to be diagnosed as hypertension, to have higher value of WC, BMI, WHR, WHtR, VAI, UA, TG, FBG and Hba1c (all P<0.05). Moreover, males with diabetes have more possibility to be a smoker, to belong to Han nationality, to have lower levels of physical activity, to have higher value of TC, ALT and lower level of HDL-C. Among 4,125 female subjects in *Table 2*, we could get the same populational characteristics without educational levels, value of LDL-C. Females with diabetes were more likely to have higher value of LDL-C (P<0.05). As for the relationship between educational levels and diabetes, the χ^2 test shows that the proportion of high school or above with diabetes (12.4%) was significantly lower than those without diabetes (20.6%) and it's the same as junior high school. Conversely, the proportion of illiteracy and primary school with diabetes was higher than those without diabetes.

Associations of quartile (Q) of adiposity indicators with diabetes in the 2009 CHNS

Multivariable-adjusted logistic regression model is applied to examine the significant and positive relationship between the quartile (Q) of adiposity indicators with prevalence rate of diabetes in participants. After progressive adjustments for current smoker (yes or no), age, education, Han nationality, physical activity (MET-h/week), hypertension (yes or no), energy intake (kcal/d), TC, *Table 3* demonstrates that participants with the highest quartile were most likely to be diagnosed with diabetes compared with those with the lowest quartile of VAI (adjusted OR: 4.347, 95% CI: 3.411–5.541). Multivariable-adjusted logistic regression model in *Table 4* shows males with the highest quartile had significantly increased likelihood of having diabetes compared with those with the lowest quartile of WC (adjusted OR: 4.626, 95% CI: 3.194–6.699), BMI (adjusted OR: 3.335, 95% CI: 2.377–4.678), WHR (adjusted OR: 3.439, 95% CI: 2.443–4.841), WHtR (adjusted OR: 5.002, 95% CI: 3.431–7.293) and VAI (adjusted OR: 5.189, 95% CI: 3.692–7.294). *Table 5* shows the adjusted OR and its 95% confidence intervals (CI) for the diabetes prevalence rate in the highest quartile compared with the lowest one, including WC (adjusted OR: 3.166, 95% CI: 2.219–4.519), BMI (adjusted OR: 3.475, 95% CI: 2.444–4.942), WHR (adjusted OR: 2.643, 95% CI: 1.840–3.795), WHtR (adjusted OR: 2.869, 95% CI: 1.957–4.204) and VAI (adjusted OR: 3.935, 95% CI: 2.718–5.696). Above all, females in the highest quartiles of VAI, BMI and WC were more likely to have diabetes than those in highest quartiles of WHR and WHtR. Instead, *Table 4* shows the highest quartiles of VAI and WHtR in males were almost 1.5 times more likely to have diabetes than the highest quartiles of

Table 1 Characteristics of the male subjects according to the occurrence of diabetes

Characteristics	Total	With diabetes	Without diabetes	P value
Participants (n)	3,805	439	3,366	
Age (years)	50.4±15.1	56.3±12.5	49.6±15.2	<0.001
Han nationality (%)	3,378 (88.8)	405 (91.6)	2,973 (87.9)	0.014
Current smoker (%)	2,347 (61.7)	250 (6.3)	2,097 (4.0)	0.030
Alcohol consumption (%)	2,275 (59.8)	248 (7.8)	2,027 (9.1)	0.134
Hypertension (%)	479 (12.6)	117 (33.9)	362 (11.3)	<0.001
Physical activity (MET-h/w)	89.2 (28.0–206.3)	67.9 (13.4–165.6)	93.7 (29.3–210.6)	<0.001
Energy intake (kcal/d)	2,284.9 (1,875.8–2,721.6)	2,244.5 (1,828.0–2,658.5)	2,292.9 (1,878.8–2,737.4)	<0.001
Educational level				0.481
Illiteracy	560 (14.7)	69 (15.7)	491 (14.6)	
Primary school	733 (19.3)	91 (20.7)	642 (19.1)	
Junior high school	1,453 (38.2)	153 (34.9)	1,300 (38.6)	
High school or above	1,059 (27.8)	126 (28.7)	933 (27.7)	
WC (cm)	84.3±10.2	90.4±10.0	83.5±9.9	<0.001
BMI (kg/m^2)	23.3±3.4	25.0±3.6	23.1±3.3	<0.001
WHtR	0.51±0.06	0.54±0.06	0.50±0.06	<0.001
WHR	0.89±0.07	0.92±0.06	0.89±0.07	<0.001
VAI	1.9±3.1	3.8±5.7	1.7±2.4	<0.001
UA (μmol/L)	355.5±112.0	389.2±178.7	351.1±99.3	<0.001
HDL-C (mmol/L)	1.4±0.5	1.3±0.8	1.4±0.5	<0.001
LDL-C (mmol/L)	2.9±1.0	2.9±1.1	2.9±0.9	0.817
ALT (U/L)	27.6±22.6	30.0±23.1	27.3±22.6	0.017
TC (mmol/L)	4.8±1.0	5.2±1.2	4.8±0.9	<0.001
TG (mmol/L)	1.7±1.6	2.8±3.0	1.5±1.2	<0.001
FBG (mmol/L)	5.5±1.6	8.5±3.1	5.1±0.6	<0.001
Hba1c (%)	5.6±1.0	7.2±1.9	5.4±0.6	<0.001

Values are expressed as means ± SDs or medians (IQRs) for continuous variables and numbers (percentages, %) for categorical variables. Characteristics of subjects were compared using two-sample t-test or the Mann-Whitney U test for continuous variables and a χ^2 test for categorical variables. CHNS, the China health and nutrition survey; BMI, body mass index; WC, waist circumference; VAI, visceral adiposity index; WHtR, waist-height ratio; WHR, waist-to-hip ratio; UA, uric acid; ALT, alanine transaminase; HbA1c, hemoglobin A1c; FBG, fasting blood glucose; TG, total triglycerides; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; MET, metabolic equivalent.

BMI and the WHR.

Predictable values of adiposity indicators for diabetes

Predictive potential of five adiposity indicators were validated by the area under the receiver operator characteristic curve (AUROC) in *Figure 1*. *Table 6* and *Figure 1A* shows that AUROC of VAI, BMI, WC, WHtR and WHR were 0.694 (95% CI: 0.675–0.714), 0.663 (95% CI: 0.644–0.683), 0.700 (95% CI: 0.681–0.719), 0.697 (95% CI: 0.678–0.715) and 0.668 (95% CI: 0.649–0.687). For females, VAI had the highest AUROC values for diabetes

Table 2 Characteristics of the female subjects according to the occurrence of diabetes

Characteristics	Total	With diabetes	Without diabetes	P value
Participants (n)	4,125	395	3,730	
Age (years)	50.2±14.5	59.8±11.5	49.2±14.4	<0.001
Han nationality (%)	3,639 (88.2)	362 (91.6)	3,277 (87.9)	0.026
Current smoker (%)	175 (4.2)	25 (6.3)	150 (4.0)	0.030
Alcohol consumption (%)	370 (9.0)	31 (7.8)	339 (9.1)	0.412
Hypertension (%)	555 (13.5)	134 (33.9)	421 (11.3)	<0.001
Physical activity (MET-h/w)	105.4 (62.5–185.6)	80.2 (55.0–135.1)	108.2 (63.8–190.2)	<0.001
Energy intake (kcal/d)	1,924.1 (1,579.7–2,292.6)	1,808.0 (1,478.3–2,180.5)	1,939.2 (1,589.4–2,300.5)	<0.001
Educational level (%)				<0.001
Illiteracy	1,266 (30.7)	168 (42.5)	1,098 (29.4)	
Primary school	856 (20.8)	97 (24.6)	759 (20.3)	
Junior high school	1,184 (28.7)	81 (20.5)	1,103 (29.6)	
High school or above	819 (19.9)	49 (12.4)	770 (20.6)	
WC (cm)	81.2±10.2	88.1±10.6	80.5±9.8	<0.001
BMI (kg/m^2)	23.4±3.5	25.4±3.8	23.2±3.4	<0.001
WHtR	0.52±0.07	0.57±0.07	0.52±0.06	<0.001
WHR	0.86±0.08	0.90±0.07	0.86±0.08	<0.001
VAI	2.2±2.6	3.9±5.4	2.0±2.0	<0.001
UA (µmol/L)	266.8±79.6	310.9±103.6	262.1±75.1	<0.001
HDL-C (mmol/L)	1.5±0.4	1.5±0.4	1.4±0.4	<0.001
LDL-C (mmol/L)	3.0±1.0	3.4±1.2	3.0±0.9	<0.001
ALT (U/L)	21.4±17.7	25.2±20.8	21.0±17.3	<0.001
TC (mmol/L)	4.9±1.1	5.4±1.0	4.8±1.1	<0.001
TG (mmol/L)	1.5±1.0	2.2±1.8	1.4±0.9	<0.001
FBG (mmol/L)	5.3±1.3	7.7±2.7	5.1±0.6	<0.001
HbA1c (%)	5.6±0.9	7.2±1.9	5.4±0.6	<0.001

Values are expressed as means ± SDs or medians (IQRs) for continuous variables and numbers (percentages, %) for categorical variables. Characteristics of subjects were compared using two-sample *t*-test or the Mann-Whitney U test for continuous variables and a χ^2 test for categorical variables. CHNS, the China health and nutrition survey; BMI, body mass index; WC, waist circumference; VAI, visceral adiposity index; WHtR, waist-height ratio; WHR, waist-to-hip ratio; UA, uric acid; ALT, alanine transaminase; HbA1c, hemoglobin A1c; FBG, fasting blood glucose; TG, total triglycerides; TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; MET, metabolic equivalent.

(AUROC =0.711, 95% CI: 0.684–0.738). In other words, it had a better accuracy to predict prevalence of diabetes than other adiposity indicators including WHtR (AUROC =0.705, 95% CI: 0.677–0.732), WC (AUROC =0.703, 95% CI: 0.676–0.731), BMI (AUROC =0.668, 95% CI: 0.640–0.697) and WHR (AUROC =0.666, 95% CI: 0.638–0.693). Accordingly, the sensitivity and specificity of the VAI were 69.9% and 64.5% respectively in *Table 6*. The optimal cut-off points were determined by Youden's index, which was used to estimate the performance of adiposity indicators.

Table 3 Multivariable-adjusted odds ratios (and 95% CIs) of diabetes according to quartile (Q) of WC, BMI, WHR, WHtR, and VAI scores in the 2009 CHNS (n=7,930)

Variable	Q1	Q2	Q3	Q4	p-trend
WC (cm)	<75.0000	75.0000–82.0000	82.0000–90.0000	>90.0000	
Participants, n (%)	2,016 (25.4)	1,956 (24.7)	1,958 (24.7)	2,000 (25.2)	
OR (95% CI)[1]	Ref	1.734 (1.297–2.319)	3.155 (2.414–4.124)	6.553 (5.093–8.433)	<0.001
Adjusted β (95% CI)[2]	Ref	1.494 (1.114–2.003)	2.597 (1.979–3.406)	5.109 (3.954–6.601)	<0.001
Adjusted β (95% CI)[3]	Ref	1.375 (1.023–1.849)	2.295 (1.744–3.019)	4.237 (3.265–5.499)	<0.001
BMI (kg/m^2)	<20.9026	20.9026–23.0884	23.0884–25.5394	>25.5394	
Participants, n (%)	1,982 (25.0)	1,983 (25.0)	1,983 (25.0)	1,982 (25.0)	
OR (95% CI)[1]	Ref	1.304 (0.999–1.702)	2.514 (1.976–3.199)	4.133 (3.285–5.199)	<0.001
Adjusted β (95% CI)[2]	Ref	1.338 (1.020–1.756)	2.481 (1.939–3.175)	4.195 (3.312–5.175)	<0.001
Adjusted β (95% CI)[3]	Ref	1.195 (0.908–1.572)	2.130 (1.660–2.733)	3.312 (2.601–4.218)	<0.001
WHR	<0.8242	0.8242–0.8719	0.8719–0.9188	>0.9188	
Participants, n (%)	1,982 (25.0)	1,983 (25.0)	1,985 (25.0)	1,980 (25.0)	
OR (95% CI)[1]	Ref	1.536 (1.167–2.020)	2.782 (2.163–3.579)	4.944 (3.892–6.281)	<0.001
Adjusted β (95% CI)[2]	Ref	1.338 (1.014–1.766)	2.238 (1.731–2.893)	3.661 (2.863–4.682)	<0.001
Adjusted β (95% CI)[3]	Ref	1.291 (0.975–1.707)	2.042 (1.576–2.647)	3.199 (2.493–4.104)	<0.001
WHtR	<0.4684	0.4684–0.5125	0.5125–0.5579	>0.5579	
Participants, n (%)	1,982 (25.0)	1,984 (25.0)	1,981 (25.0)	1,983 (25.0)	
OR (95% CI)[1]	Ref	1.726 (1.295–2.301)	3.003 (2.300–3.921)	6.323 (4.919–8.130)	<0.001
Adjusted OR (95% CI)[2]	Ref	1.458 (1.090–1.950)	2.358 (1.798–3.092)	4.642 (3.586–6.009)	<0.001
Adjusted OR (95% CI)[3]	Ref	1.322 (0.986–1.772)	2.042 (1.552–2.687)	3.760 (2.891–4.890)	<0.001
VAI	<0.8672	0.8672–1.3899	1.3899–2.3456	>2.3456	
Participants, n (%)	1,982 (25.0)	1,983 (25.0)	1,983 (25.0)	1,982 (25.0)	
OR (95% CI)[1]	Ref	1.141 (0.862–1.511)	2.156 (1.676–2.772)	5.368 (4.264–6.759)	<0.001
Adjusted OR (95% CI)[2]	Ref	1.156 (0.870–1.536)	2.124 (1.644–2.746)	5.273 (4.164–6.678)	<0.001
Adjusted OR (95% CI)[3]	Ref	1.109 (0.833–1.476)	1.908 (1.471–2.475)	4.347 (3.411–5.541)	<0.001

[1], Model 1: unadjusted; [2], Model 2: adjusted for current smoker (yes or no), age, education (Illiteracy, primary school, junior high school, high school or above), Han nationality (yes or no); [3], Model 3: adjusted for all variables in Model 2 as well as physical activity (MET-h/week), energy intake (kcal/d), hypertension (yes or no), TC. Q, quintile; CI, confidence interval; Ref, reference.

The appropriate cut-off for adiposity indicators among females were 84.2 cm for WC, 23.2 kg/m^2 for BMI, 0.878 for WHR, and 0.534 for WHtR and 1.878 for VAI. While for males, WHtR (AUROC =0.701, 95% CI: 0.676–0.727) was the most accurate indicator to predict prevalence of diabetes. In table 6, the appropriate cut-off for adiposity indicators among males were 87 cm for WC, 22.7 kg/m^2 for BMI, 0.898 for WHR, and 0.520 for WHtR and 2.323 for VAI. The most sensitive screening indicator is BMI for both men and women whose sensitivity is 76.5% and 71.9% respectively.

Discussion

In cross-sectional analyses of 3,805 male and 4,125 female

Table 4 Multivariable-adjusted odds ratios (and 95% CIs) of diabetes according to quartile (Q) of WC, BMI, WHR, WHtR, and VAI scores in male participants (n=3,805)

Variable	Q1	Q2	Q3	Q4	p-trend
WC (kg/m^2)	<77.0000	77.0000–84.0000	84.0000–91.0000	>91.0000	
Participants, n (%)	919 (24.2)	1,007 (26.5)	946 (24.9)	933 (24.5)	
OR (95% CI)[1]	Ref	1.686 (1.127–2.521)	3.531 (2.437–5.116)	6.235 (4.365–8.906)	<0.001
Adjusted β (95% CI)[2]	Ref	1.586 (1.057–2.380)	3.205 (2.200–4.671)	5.599 (3.895–8.046)	<0.001
Adjusted β (95% CI)[3]	Ref	1.480 (0.984–2.225)	2.855 (1.951–4.177)	4.626 (3.194–6.699)	<0.001
BMI (kg/m^2)	<20.8581	20.8581–23.0915	23.0915–25.4234	>25.4234	
Participants, n (%)	951 (25.0)	952 (25.0)	951 (25.0)	951 (25.0)	
OR (95% CI)[1]	Ref	1.339 (0.928–1.930)	2.607 (1.871–3.631)	4.012 (2.919–5.514)	<0.001
Adjusted β (95% CI)[2]	Ref	1.374 (0.948–1.990)	2.655 (1.892–3.726)	4.233 (3.045–5.883)	<0.001
Adjusted β (95% CI)[3]	Ref	1.248 (0.859–1.814)	2.298 (1.630–3.238)	3.335 (2.377–4.678)	<0.001
WHR	<0.8448	0.8448–0.8878	0.8878–0.9326	>0.9326	
Participants, n (%)	951 (25.0)	951 (25.0)	949 (24.9)	954 (25.1)	
OR (95% CI)[1]	Ref	1.623 (1.113–2.367)	2.999 (2.119–4.244)	4.783 (3.427–6.677)	<0.001
Adjusted β (95% CI)[2]	Ref	1.524 (1.042–2.228)	2.589 (1.822–3.680)	4.057 (2.896–5.684)	<0.001
Adjusted β (95% CI)[3]	Ref	1.442 (0.984–2.113)	2.326 (1.632–3.315)	3.439 (2.443–4.841)	<0.001
WHtR	<0.46346	0.46346–0.5047	0.5047–0.5455	>0.5455	
Participants, n (%)	951 (25.0)	950 (25.0)	953 (25.0)	951 (25.0)	
OR (95% CI)[1]	Ref	2.239 (1.491–3.362)	3.389 (2.301–4.990)	7.380 (5.117–10.643)	<0.001
Adjusted OR (95% CI)[2]	Ref	2.060 (1.369–3.101)	2.891 (1.956–4.274)	6.050 (4.176–8.764)	<0.001
Adjusted OR (95% CI)[3]	Ref	1.902 (1.261–2.870)	2.583 (1.742–3.831)	5.002 (3.431–7.293)	<0.001
VAI	<0.7447	0.7447–1.2037	1.2037–2.0856	>2.0856	
Participants, n (%)	951 (25.0)	951 (25.0)	952 (25.0)	951 (25.0)	
OR (95% CI)[1]	Ref	1.300 (0.888–1.904)	2.186 (1.540–3.104)	5.488 (3.977–7.572)	<0.001
Adjusted OR (95% CI)[2]	Ref	1.367 (0.930–2.011)	2.323 (1.625–3.322)	6.289 (4.514–8.763)	<0.001
Adjusted OR (95% CI)[3]	Ref	1.303 (0.885–1.920)	2.074 (1.445–2.978)	5.189 (3.692–7.294)	<0.001

[1], Model 1: unadjusted; [2], Model 2: adjusted for current smoker (yes or no), age, education (Illiteracy, primary school, junior high school, high school or above), Han nationality (yes or no); [3], Model 3: adjusted for all variables in Model 2 as well as physical activity (MET-h/week), energy intake (kcal/d), hypertension (yes or no), TC. Q, quintile; CI, confidence interval; Ref, reference.

participants in 2009 CHNS, we could find that risk factors of diabetes in Chinese were age, obesity, Han nationality, high BP and other characteristics. Five adiposity indicators including BMI, WC, WHR, WHtR and VAI, which can reflect the degree of obesity, were all confirmed to be related to the risk of diabetes. From all participants we can find that WC, WHtR and VAI are more involved with the prevalence of diabetes than BMI and WHR. As we all know, abdominal obesity can be measured by WHtR, WC and VAI, while BMI is not a suitable predictor for the percentage of body adipose. In recent years, more and more studies have revealed that ectopic fat obesity presented the greatest risk of incident type 2 diabetes (30). Although the details of the underlying mechanism about the effect of VAI, WC or WHtR on diabetes remains to be determined, abdominal obesity can induce insulin resistance, which

Table 5 Multivariable-adjusted odds ratios (and 95% CIs) of diabetes according to quartile (Q) of WC, BMI, WHR, WHtR and VAI scores in female participants (n=4,125)

Variable	Q1	Q2	Q3	Q4	p-trend
WC (kg/m^2)	<74.0000	74.0000–80.1000	80.1000–88.0000	>88.0000	
Participants, n (%)	1,075 (26.1)	988 (24.0)	999 (24.2)	1,063 (25.8)	
OR (95% CI)[1]	Ref	1.469 (0.979–2.205)	2.405 (1.656–3.494)	5.700 (4.052–8.017)	<0.001
Adjusted β (95% CI)[2]	Ref	1.195 (0.791–1.806)	1.744 (1.190–2.554)	3.660 (2.576–5.199)	<0.001
Adjusted β (95% CI)[3]	Ref	1.052 (0.693–1.599)	1.486 (1.009–2.189)	3.166 (2.219–4.519)	<0.001
BMI (kg/m^2)	<20.9566	20.9566–23.0701	23.0701–25.6164	>25.6164	
Participants, n (%)	1,031 (25.0)	1,031 (25.0)	1,032 (25.0)	1,031 (25.0)	
OR (95% CI)[1]	Ref	1.370 (0.926–2.027)	2.529 (1.771–3.610)	4.468 (3.190–6.258)	<0.001
Adjusted β (95% CI)[2]	Ref	1.377 (0.921–2.057)	2.321 (1.609–3.349)	4.059 (2.867–5.746)	<0.001
Adjusted β (95% CI)[3]	Ref	1.198 (0.798–1.799)	1.996 (1.378–2.891)	3.475 (2.444–4.942)	<0.001
WHR	<0.8090	0.8090–0.8571	0.8571–0.9022	>0.9022	
Participants, n (%)	1,031 (25.0)	1,024 (24.8)	1,039 (25.2)	1,031 (25.0)	
OR (95% CI)[1]	Ref	1.634 (1.104–2.419)	2.528 (1.752–3.649)	4.893 (3.465–6.908)	<0.001
Adjusted β (95% CI)[2]	Ref	1.339 (0.898–1.997)	1.861 (1.278–2.710)	2.896 (2.019–4.154)	<0.001
Adjusted β (95% CI)[3]	Ref	1.277 (0.853–1.912)	1.695 (1.159–2.478)	2.643 (1.840–3.795)	<0.001
WHtR	<0.4718	0.4718–0.5181	0.5181–0.5648	>0.5648	
Participants, n (%)	1,030 (25.0)	1,033 (25.0)	1,031 (25.0)	1,031 (25.0)	
OR (95% CI)[1]	Ref	1.412 (0.922–2.161)	2.960 (2.021–4.336)	6.244 (4.361–8.941)	<0.001
Adjusted OR (95% CI)[2]	Ref	1.018 (0.659–1.573)	1.929 (1.301–2.859)	3.384 (2.315–4.946)	<0.001
Adjusted OR (95% CI)[3]	Ref	0.912 (0.587–1.417)	1.683 (1.129–2.508)	2.869 (1.957–4.204)	<0.001
VAI	<0.9990	0.9990–1.5460	1.5460–2.5653	>2.5653	
Participants, n (%)	1,031 (25.0)	1,031 (25.0)	1,032 (25.0)	1,031 (25.0)	
OR (95% CI)[1]	Ref	1.304 (0.846–2.010)	2.991 (2.043–4.380)	6.367 (4.449–9.114)	<0.001
Adjusted OR (95% CI)[2]	Ref	1.044 (0.672–1.621)	2.155 (1.459–3.182)	4.392 (3.045–6.336)	<0.001
Adjusted OR (95% CI)[3]	Ref	1.017 (0.652–1.586)	2.001 (1.347–2.972)	3.935 (2.718–5.696)	<0.001

[1], Model 1: unadjusted; [2], Model 2: adjusted for current smoker (yes or no), age, education (Illiteracy, primary school, junior high school, high school or above), Han nationality (yes or no); [3], Model 3: adjusted for all variables in Model 2 as well as physical activity (MET-h/week), energy intake (kcal/d), hypertension (yes or no), TC. Q, quintile; HbA1c, hemoglobin A1c; FBG, fasting blood glucose; LDL-C, low-density lipoprotein cholesterol; CI, confidence interval; Ref, reference.

means a defective response to insulin in peripheral tissues (31).

There have been a few studies showing that adiposity indicators would be associated with diabetes. Some scholars thought WHtR should be considered the best anthropometric indices in predicting diabetes risk (32). VAI was thought to be positively associated with the risk of increased incidence of new-onset type 2 diabetes in hypertensive patients (33). These articles did not talk about the difference between men and women, which is precisely our advantage and new information. In Taipei, VAI may serve as a perfect clinical indicator of diabetes among older adult Chinese, especially in women. Our research not only agreed with theirs, but also complement the features of young women (34). Populations from Northern Nigerian were used to demonstrate that WHtR had the highest

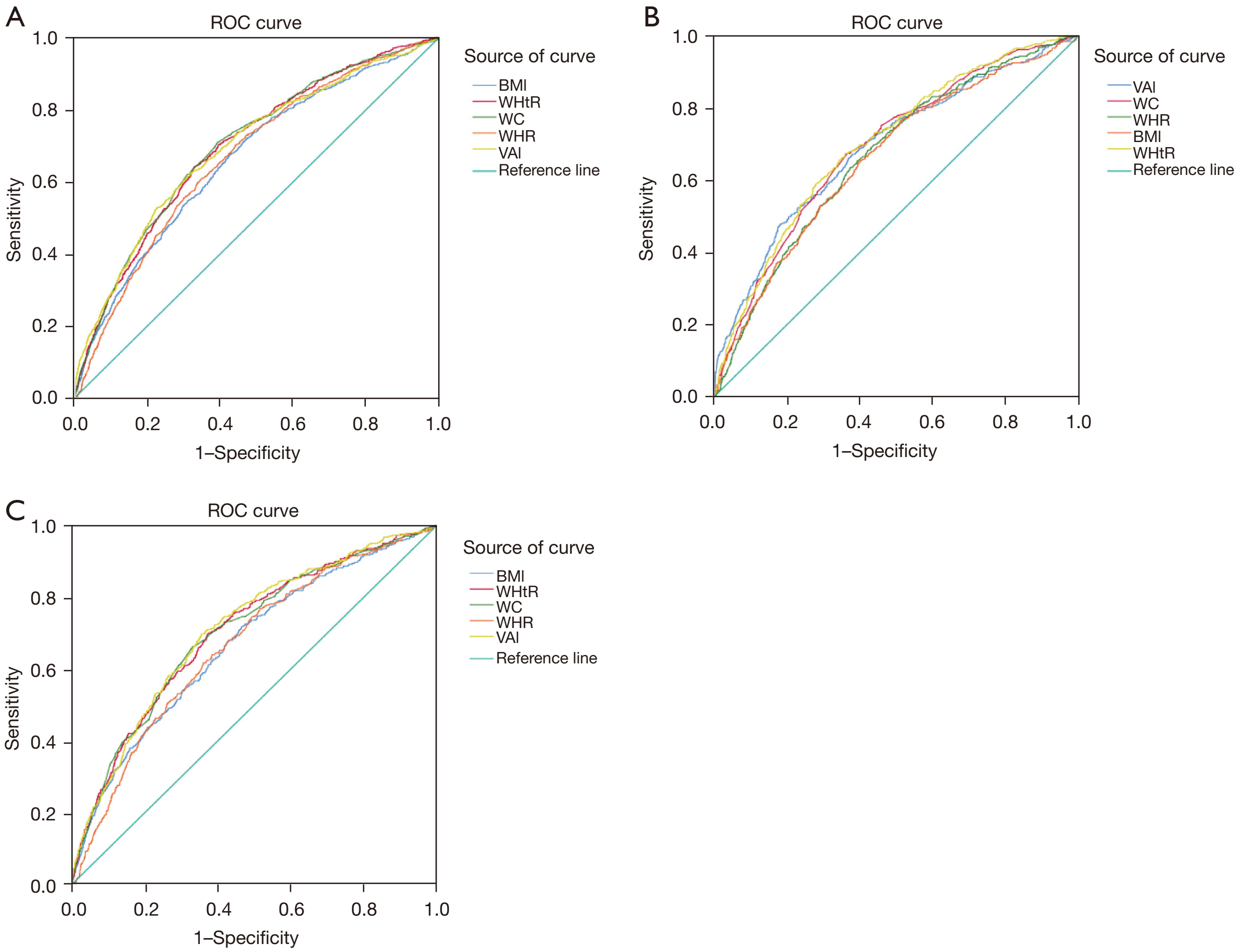

Figure 1 Application of ROC curve approach for five adiposity indicators in diagnostical tests. The ROC curves of BMI, WHtR, WC, WHR and VAI for diabetes among all participants (A), men (B) and women (C). Application of ROC curve approach for five adiposity indicators in diagnostical tests. ROC curve, receiver operating characteristic curve; BMI, body mass index; WHtR, waist-height ratio; WC, waist circumference; WHR, waist-to-hip ratio; VAI, visceral adiposity index.

predictive power for glucose intolerance compared to BMI, WC, and WHR (35). Some Mexican scholars provided evidence that WHtR could predict the risk assessment of type 2 diabetes mellitus in Mexican population (36). In addition, Rasmieh Alzeidan emphasized that waist height ratio showed a good diagnostic performance for metabolic syndrome among Saudis (37). It should be noted that WC and its change, are more strongly associated with the risk of type 2 diabetes than BMI, and changes in body weight among Chinese adults, and it's essentially the same in our results (38). Some Chinese scholars claim that WC and WHtR are more closely related to diabetes than BMI and WHR among participants over 40 years old in Jilin province in North China, especially in females, and our study are consistent with their results (39). Whereas, ethnic and racial differences may explain the discrepancy in cut-off values between different studies. WHtR of 0.5 is used as the optimum cut-off for predicting diabetes globally. When it comes to our study, WHtR of 0.534 is recommended as the optimum cut-off for predicting diabetes in China. The recommended cut-offs regarding central obesity in China are WC ≥90 cm for men and WC ≥85 for women. Compared to these recommendations, our data demonstrated a similar cut-off value for WC (87.0 cm) in males, but a restrict value in women (84.2 cm). The most sensitive screening indicator is BMI for both men and women whose sensitivity is 76.5% and 71.9% respectively.

Table 6 The area under the curve and the optimum cut-off points of the adiposity indicators for diabetes

Variables	AUROC (95% CI)	P	Sensitivity (%)	Specificity (%)	Cut-offs	Youden's index
Total						
WC	0.700 (0.681–0.719)	<0.001	71.0	60.8	84.2	0.317
BMI	0.663 (0.644–0.683)	<0.001	68.0	56.9	23.5	0.249
WHR	0.668 (0.649–0.687)	<0.001	70.4	55.7	0.878	0.261
WHtR	0.697 (0.678–0.715)	<0.001	64.3	67.0	0.534	0.313
VAI	0.694 (0.675–0.714)	<0.001	62.7	67.9	1.833	0.306
Male						
WC	0.692 (0.666–0.718)	<0.001	67.4	63.5	87.0	0.309
BMI	0.660 (0.633–0.687)	<0.001	76.5	48.9	22.7	0.254
WHR	0.667 (0.641–0.693)	<0.001	68.1	58.0	0.898	0.261
WHtR	0.701 (0.676–0.727)	<0.001	67.4	64.1	0.520	0.315
VAI	0.691 (0.663–0.719)	<0.001	47.8	81.8	2.323	0.297
Female						
WC	0.703 (0.676–0.731)	<0.001	66.3	67.0	84.2	0.333
BMI	0.668 (0.640–0.697)	<0.001	71.9	53.4	23.2	0.253
WHR	0.666 (0.638–0.693)	<0.001	61.8	64.0	0.878	0.258
WHtR	0.705 (0.677–0.732)	<0.001	69.9	62.8	0.534	0.327
VAI	0.711 (0.684–0.738)	<0.001	69.9	64.5	1.878	0.344

The area under the receiver operator characteristic curve, optimal cut-off points, sensitivity and specificity were determined by Youden's index. AUROC, area under the receiver operating characteristic; BMI, body mass index; WC, waist circumference; VAI, visceral adiposity index; WHtR, waist-height ratio; WHR, waist-to-hip ratio.

A novel finding of the study is that, different from men, the value of VAI in diagnosing diabetes is higher than WC or WHtR in Chinese women. VAI is proposed as a reliable and comprehensive indicator of determining visceral adipose. Additionally, excessively deposited visceral fat will secrete a wide variety of adipokines and inflammatory mediators, including tumor necrosis factor-α (TNF-α), interleukin (IL)-6, and macrophage chemoattractant protein-1 (MCP-1), resulting in insulin resistance and accelerating the occurrence of diabetes. The prevalence of abdominal obesity in women was higher than that in men, which might be attributed to hormonal levels (40). The Chinese National Youth Risk Behavior Surveillance showed that 23.6% of girls and 9.1% boys tried to restrict their diets to lose weight (41). All above illustrate that we are facing a worrying situation where the prevalence of abdominal obesity would increase more rapidly in Chinese women. Above all, although VAI should take TG and HDL into consideration, women should pay more attention to this indicator to prevent diabetes.

Strengths of this study consist of the nationwide, population-based design, and adjustment for as many confounders as possible. On the other hand, our limitation is that intrinsic imperfection of the cross-sectional study would confine the analysis of the neglected causal relationship. It's a pity to admit our inability to distinguish between type 1 diabetes and type 2 diabetes.

In conclusion, our findings indicate that WC, WHtR, BMI, WHR and VAI are all independent risk factors for diabetes among Chinese adults. WHtR is the most accurate indicator for diabetes in men, while VAI for women. The optimal cut-offs regarding diabetes in Chinese are WHtR ≥0.520 for men and VAI ≥1.878 for women. The most sensitive screening indicator is BMI for both men and women.

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Footnote

Reporting Checklist: The authors have completed the STARD reporting checklist. Available at https://apm.amegroups.com/article/view/10.21037/apm-21-3072/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://apm.amegroups.com/article/view/10.21037/apm-21-3072/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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