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Association between obesity indices and type 2 diabetes mellitus among middle-aged and elderly people in Jinan, China: a cross-sectional study

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ABSTRACT

Background: The relationship between obesity and type 2 diabetes mellitus (T2DM) varies with geographical area and race.

Objectives: To investigate the prevalence of T2DM and the proportion of subjects with undiagnosed T2DM. In addition, to compare the associations between different obesity indices and T2DM for middle-aged and elderly people from six communities in Jinan, China.

Setting: A cross-sectional study was designed and the study subjects were chosen from blocks which were randomly selected in the 6 communities of Jinan, China in 2011–2012.

Participants: A total of 3277 residents aged ≥50 years were eligible for this study, but 1563 people were excluded because they did not provide anthropometric data such as height, weight, waist circumference (WC), hip circumference, systolic blood pressure, diastolic blood pressure, fasting plasma glucose, triglyceride (TG), total cholesterol (TC) or information about their current medication use. Hence, 1714 participants were included in the final data analysis.

Results: The prevalence of T2DM among people aged ≥50 years was 16.6% (19.3% for men and 15.3% for women) and the proportion of patients with undiagnosed T2DM was 32.7%. Compared with the lowest levels of body mass index (BMI), WC, waist-to-hip ratio or waist-to-stature ratio (WSR), the ORs and 95% CIs of the highest levels for men, after adjusting for age, smoking, alcohol drinking, regular exercise, hypertension, TG and TC, were 1.607 (0.804 to 3.210), 2.189 (1.118 to 4.285), 1.873 (0.968 to 3.623) and 2.572 (1.301 to 5.083), respectively, and for women, 2.764 (1.622 to 4.712), 2.407 (1.455 to 3.985), 2.500 (1.484 to 4.211) and 2.452 (1.447 to 4.155), respectively.

Conclusions: Among adults aged ≥50 years in Jinan, China, the best indicator of the relationship between obesity and T2DM is WSR for men and BMI for women, respectively.

Strengths and limitations of this study

- The obesity indexes used for diabetes screening by sex for Chinese adults aged ≥50 years are proposed for the first time in this study.
- Compared with a cohort study, cross-sectional design is more suitable for determining screening indexes of type 2 diabetes mellitus (T2DM).
- The best index of obesity adopted in the screening model for T2DM is different from that in the prediction model.
- Selection bias might have been present as about half of the study subjects did not take part in the physical examination.

INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a worldwide public health problem that increases mortality and affects quality of life. It is estimated that the number of people with T2DM worldwide will increase from 246 million in 2012[1] to 592 million by 2035.[2] The prevalence of T2DM has increased more rapidly in China, from 1% in 1980 to 5% in 2001[3] and rose to 9.7% in 2008, affecting nearly 92.4 million adults.[4] An overwhelmingly serious problem is that T2DM often cannot be diagnosed until complications appear.[5] The proportion of undiagnosed cases of T2DM in China was found to be 60%.[4] It is thus important to make efforts to detect and diagnose T2DM earlier in its course, and the most suitable indexes for identifying individuals at high risk in the communities must be determined as soon as possible.

Obesity is a major independent and modifiable risk factor for T2DM and many epidemiological studies have suggested a

progressive increase in the prevalence of T2DM with obesity.[6 7] More importantly, indexes of obesity play an unusual role in screening T2DM and determining high-risk individuals. Several measurements of obesity, including body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-stature ratio (WSR), are significantly associated with T2DM.[8 9] BMI is the marker most commonly used to identify the risk of future T2DM;[10] however, it cannot be used to distinguish between muscle and fat.[11] Compared with BMI, central obesity indices, such as WC, WHR and WSR, appeared to be more strongly associated with T2DM.[12 13] Some studies have shown that WC is better than WHR and BMI,[14 15] whereas other studies reported WSR to be the best indicator for the relationship between obesity and T2DM.[16 17] However, several studies indicated that BMI was as powerful as WC and WHR,[18 19] and BMI has been reported to be a better index than WC for the relationship between obesity and T2DM.[20] Although the above four simple and economical indices of obesity have all been associated with T2DM, which of these is the best has been debated. Body fat distribution varies with age, sex and ethnicity;[21] the relationship between obesity and T2DM may also differ according to these factors. Diabetes screening is paramount for adults aged ≥50 years owing to their higher risks, and thus the index most suitable for representing the relationship between obesity and T2DM should be used for adults aged ≥50 years in northern China.

To date, few studies have examined and compared the relationship between obesity indices and T2DM among middle-aged and elderly people in northern Chinese urban communities. Thus, we investigated the prevalence of T2DM and the proportion of people with undiagnosed T2DM and compared the associations between obesity indices and T2DM in order to determine the best obesity index to use for T2DM screening of middle-aged and elderly people in northern China.

MATERIALS AND METHODS

Study population

The subjects were from randomly selected blocks located in the six communities of Jinan, China in 2011–2012. The inclusion criteria for the participants included (1) age ≥50 years, (2) the ability to answer the questionnaire and (3) residence in the selected communities for >6 months in the past year. A total of 3277 residents aged ≥50 years completed the questionnaire in this study; 1563 people were excluded because they did not provide anthropometric data such as height, weight, WC, hip circumference, systolic blood pressure (SBP), diastolic blood pressure (DBP), fasting plasma glucose (FPG), triglyceride (TG), total cholesterol (TC) or information about their current medication use. A total of 1714 participants were included in the final data analysis.

Investigation and measurements

Trained interviewers administered a standardised questionnaire to obtain demographic information, including the subjects' age, sex, current smoking status (yes or no), current alcohol intake (yes or no) and regular exercise frequency (<1 time per week, 1–2 times per week, 3–4 times per week, 5–7 times per week or ≥8 times per week). After an overnight fast of at least 12 hours, all subjects underwent a standardised medical examination that included routine anthropometric, clinical and laboratory tests. Blood pressure (BP) was measured in the right arm by trained examiners using a mercury sphygmomanometer according to a standard protocol. Three BP measurements were obtained with an interval of from 5 to 15 min and the average of the three readings was chosen as the BP value for each subject. The laboratory tests included TG, TC and FPG; subjects with abnormal results were assessed again on a different day. The anthropometric measurements were taken after the participants had removed their shoes and any heavy clothing or belts. Each subject's height, weight, WC and hip circumference were measured by experienced nurses. The WC was measured at the level midway between the lower rib margin and the iliac crest while the participants breathed out gently. The hip circumference measurement was taken at the maximal gluteal protrusion. The BMI, WHR and WSR were calculated as the weight (kg)/height^2 (m^2), WC (cm)/hip (cm) and WC (cm)/stature (cm), respectively. This study was approved by the ethics committee of the School of Public Health of Shandong University and written informed consent was obtained from each participant.

Definition of obesity, hypertension, T2DM and undiagnosed T2DM

Obesity was defined as a BMI≥28 according to the standard criteria of the Chinese Obesity Working Group.[22] Hypertension was defined as an SBP≥140 mm Hg or a DBP≥90 mm Hg at least three times or the self-reported current use of antihypertensive medication. T2DM was defined as FPG≥7.0 mmol/L at least twice, HbA1c≥6.5% and FPG≥7.0 mmol/L, 2-hour glucose after an oral glucose tolerance test ≥11.1 mmol/L or anti-diabetic medication use or self-reported T2DM confirmed by either FPG≥7.0 mmol/L or HbA1c≥6.5%. Undiagnosed T2DM was identified as an FPG≥7.0 mmol/L when neither a history of diabetes nor hypoglycaemic drug use was present.[23]

Anthropometric indices and potential confounding factors

Before fitting logistic regression models, the original continuous anthropometric indices, such as BMI, WC, WHR and WSR, were categorised into four levels using the three quartiles of P25, P50 and P75 as cut-off values, respectively, according to gender. Different potential confounding factors were also considered in the four logistic regression models.

Statistical analysis

Descriptive statistics of all variables were obtained according to gender and diabetes status. Numerical data were expressed as means±SD or median and quartile range according to whether their distribution was normal or skewed as judged by a histogram. A two-sample t-test and Wilcoxon rank sum test were used to determine the group difference. Categorical variables were expressed as percentages and a χ^2 test was used to compare differences for categorical data. Four logistic regression models were generated according to different confounding factors. In the first model no variable was adjusted for while in the second model adjustment for age only was made. The third model contained adjustments for continuous age, smoking (yes or no), alcohol drinking (yes or no) and regular exercise frequency (<1 time per week, 1–2 times per week, 3–4 times per week, 5–7 times per week or ≥8 times per week); adjustments for hypertension (yes or no), continuous TG and cholesterol were added to the fourth model. Categorical BMI, WC, WHR and WSR values were the independent variables in the four models. The areas under the receiver operating characteristic curves (AUCs) and their 95% CIs were computed for BMI, WC, WHR or WSR in the four models, respectively, according to gender. p<0.05 was considered statistically significant and SPSS (V.20.0) was used to perform the analyses.

RESULTS

A total of 1714 people (555 men and 1159 women) aged ≥50 years were included in this study. The characteristics of the study participants according to gender are summarised in table 1. The median age was 64.00 (14.00) years for men and 62.00 (15.00) years for women; a significant difference for age was found between men and women (p=0.035). Participants in the male group were taller, heavier, had a greater WC, WHR, DBP and FPG, a higher prevalence of hypertension and T2DM and a higher incidence of a current alcohol drinking and smoking than those in female group (p<0.05). However, WSR, TG and TC measurements and the prevalence of obesity in the female group were significantly higher than those in the male group (p<0.05).

Table 2 shows a comparison of characteristics of the study participants between the diabetic and non-diabetic groups. Participants in the diabetic group were older,

Table 1 Summary statistics and comparison of anthropometric measurements according to gender

Characteristics	Men (n=555)	Women (n=1159)	Total (n=1714)	p Value
Age (years), median	64.00 (14.00)	62.00 (15.00)	63.00 (15.00)	0.035
Height (cm)	169.07±5.90	157.29±5.78	161.11±8.01	<0.001
Weight (kg)	72.32±10.20	62.87±9.75	65.93±10.84	<0.001
Hip (cm)	100.75±6.81	100.68±8.31	100.70±7.86	0.074
WC (cm)	91.36±9.40	87.13±10.13	88.50±10.09	<0.001
BMI (kg/m^2)	25.27±3.11	25.40±3.68	25.36±3.50	0.434
WHR	0.91±0.06	0.86±0.06	0.88±0.07	<0.001
WSR	0.54±0.06	0.55±0.07	0.55±0.06	<0.001
SBP (mm Hg)	138.00 (30.00)	130.00 (30.00)	130.00 (30.00)	0.131
DBP (mm Hg)	85.00 (10.00)	80.00 (15.00)	80.00 (12.00)	<0.001
FPG (mg/dL)	5.45 (1.29)	5.36 (0.96)	5.38 (1.04)	0.047
TG (mg/dL)	1.18 (0.87)	1.26 (0.85)	1.24 (0.85)	0.012
TC (mg/dL)	4.92±0.87	5.40±1.02	5.25±1.00	<0.001
Smoking, n (%)	214 (38.6)	39 (3.4)	253 (14.8)	<0.001
Alcohol drinking, n (%)	179 (32.3)	23 (2.0)	202 (11.8)	<0.001
Regular exercise, n (%)				
<1 Time per week	78 (14.1)	196 (16.9)	274 (16.0)	0.131
1~2 Times per week	40 (7.2)	63 (5.4)	103 (6.0)	0.149
3~4 Times per week	55 (9.9)	120 (10.4)	175 (10.2)	0.776
5~7 Times per week	247 (44.5)	514 (44.3)	761 (44.4)	0.952
≥8 Times per week	135 (24.3)	266 (23.0)	401 (23.4)	0.530
Obesity, n (%)	92 (16.6)	254 (21.9)	346 (20.2)	0.010
Hypertension, n (%)	376 (67.7)	681 (58.8)	1057 (61.7)	<0.001
T2DM, n (%)	107 (19.3)	177 (15.3)	284 (16.6)	0.037
Undiagnosed T2DM, n (%)*	38 (35.5)	55 (31.1)	93 (32.7)	0.440

Results are shown as means±SD unless stated otherwise.
The comparison of characteristics between men and women (unpaired Student's t-test or Wilcoxon rank sum test for numerical data, χ^2 test for categorical data).
*Undiagnosed T2DM was calculated as the number of patients with undiagnosed T2DM divided by the total number of patients with T2DM in this survey.
BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; Hip, hip circumference; SBP, systolic blood pressure; T2DM, type 2 diabetes mellitus; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-to-hip ratio; WSR, waist-to-stature ratio.

Table 2 Summary statistics and a comparison of characteristics between the diabetic and non-diabetic groups

Characteristics	Diabetic (n=284)	Non-diabetic (n=1430)	p Value
Age (years), median	64.00 (13.75)	63.00 (15.00)	0.021
Height (cm)	161.56±7.67	161.02±8.08	0.300
Weight (kg)	68.64±9.53	65.39±11.00	<0.001
Hip (cm)	102.35±7.70	100.38±7.85	<0.001
WC (cm)	91.97±10.44	87.84±9.89	<0.001
BMI (kg/m^2)	26.30±3.30	25.17±3.51	<0.001
WHR	0.90±0.07	0.87±0.06	<0.001
WSR	0.57±0.07	0.55±0.06	<0.001
SBP (mm Hg)	140.00 (25.75)	130.00 (30.00)	0.007
DBP (mm Hg)	80.00 (14.00)	80.00 (10.00)	0.535
FPG (mg/dL)	7.88 (2.55)	5.26 (0.78)	<0.001
TG (mg/dL)	1.59 (1.11)	1.19 (0.81)	<0.001
TC (mg/dL)	5.39±1.34	5.22±0.91	0.034
Men, n (%)	107 (37.7)	448 (31.3)	0.037
Smoking, n (%)	39 (13.7)	214 (15.0)	0.593
Alcohol drinking, n (%)	23 (8.1)	179 (12.5)	0.035
Regular exercise, n (%)			
<1 time per week	51 (18.0)	223 (15.6)	0.321
1~2 Times per week	13 (4.6)	90 (6.3)	0.266
3~4 Times per week	29 (10.2)	146 (10.2)	0.999
5~7 Times per week	128 (45.1)	633 (44.3)	0.803
≥8 Times per week	63 (22.2)	338 (23.6)	0.597
Obesity, n (%)	74 (26.1)	272 (19.0)	0.007
Hypertension, n (%)	191 (67.3)	866 (60.6)	0.034

Results are shown as means±SD unless stated otherwise.
The comparison of characteristics between diabetic and non-diabetic (unpaired Student's *t*-test or Wilcoxon rank sum test for numerical data, χ^2 test for categorical data).
BMI, body mass index; DBP, diastolic blood pressure; FPG, fasting plasma glucose; Hip, hip circumference; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-to-hip ratio; WSR, waist-to-stature ratio.

heavier, had higher hip circumference, WC, BMI, WHR, WSR, SBP, FPG, TG and TC measurements, a higher prevalence of hypertension and obesity and a higher proportion of the men than those in the non-diabetic group (p<0.05). However, the incidence of current alcohol drinking in the non-diabetic group was significantly higher than that in the diabetic group (p<0.05).

Table 3 compares the associations between obesity indices and T2DM, after adjusting for potential confounding factors, respectively, in the male group. Compared with the lowest BMI, WC, WHR or WSR levels, the ORs and 95% CIs of the highest were 1.773 (0.943 to 3.333), 2.343 (1.247 to 4.404), 1.899 (1.019 to 3.539) and 3.003 (1.614 to 5.591), respectively, without adjustment for any variables. The ORs and 95% CIs of the highest levels were 1.861 (0.985 to 3.541), 2.241 (1.189 to 4.226), 1.806 (0.965 to 3.378) and 2.782 (1.482 to 5.224), respectively, with adjustment for age. The ORs and 95% CIs of the highest levels were 2.000 (1.036 to 3.861), 2.570 (1.343 to 4.918), 2.145 (1.126 to 4.085) and 3.183 (1.661 to 6.101), respectively, with adjustment for age, smoking, alcohol drinking and regular exercise. The ORs and 95% CIs of the highest levels were 1.607 (0.804 to 3.210), 2.189 (1.118 to 4.285), 1.873 (0.968 to 3.623) and 2.572 (1.301 to 5.083), respectively, with adjustment for age, smoking, alcohol drinking, regular exercise, hypertension, TG and TC.

Table 4 illustrates the association between obesity indices and T2DM, after adjusting for potential confounding factors, respectively, in the female group. Compared with the lowest BMI, WC, WHR or WSR levels, the ORs and 95% CIs of the highest were 3.183 (1.905 to 5.319), 2.587 (1.626 to 4.115), 2.651 (1.625 to 4.327) and 2.652 (1.644 to 4.277), respectively, without adjustment for any variables. The ORs and 95% CIs of the highest levels were 3.161 (1.890 to 5.288), 2.697 (1.661 to 4.378), 2.801 (1.677 to 4.679) and 2.862 (1.720 to 4.763), respectively, with adjustment for age. The ORs and 95% CIs of the highest levels were 3.230 (1.926 to 5.415), 2.755 (1.693 to 4.484), 2.816 (1.685 to 4.706) and 2.891 (1.733 to 4.822), with adjustment for age, smoking, alcohol drinking and regular exercise. The ORs and 95% CIs of the highest levels were 2.764 (1.622 to 4.712), 2.407 (1.455 to 3.985), 2.500 (1.484 to 4.211) and 2.452 (1.447 to 4.155), respectively, with adjustment for age, smoking, alcohol drinking, regular exercise, hypertension, TG and TC.

Table 5 shows the AUCs for BMI, WC, WHR and WSR according to gender, respectively, in the four models. The AUCs of the WSR for men in the four models were 0.608 (0.549 to 0.668), 0.614 (0.554 to 0.675), 0.679 (0.622 to 0.735), 0.703 (0.648 to 0.758), respectively. The AUC of the WSR was larger than the AUC for BMI, WC and WHR for the men. The BMI AUCs for women

Table 3 OR and 95% CI of the presence of T2DM according to quartiles of anthropometric indicators for men

Variable	n	%	Model 1	Model 2	Model 3	Model 4
BMI (kg/m^2)						
<23.43	138	24.9	Reference	Reference	Reference	Reference
23.43–	140	25.2	1.566 (0.828 to 2.961)	1.557 (0.821 to 2.954)	1.584 (0.820 to 3.057)	1.417 (0.725 to 2.769)
25.34–	141	25.4	1.693 (0.901 to 3.179)	1.811 (0.959 to 3.421)	1.861 (0.964 to 3.592)	1.686 (0.861 to 3.301)
27.08–	136	24.5	1.773 (0.943 to 3.333)	1.861 (0.985 to 3.541)	2.000 (1.036 to 3.861)	1.607 (0.804 to 3.210)
WC (cm)						
<86	160	28.8	Reference	Reference	Reference	Reference
86–	141	25.4	1.839 (0.976 to 3.463)	1.824 (0.967 to 3.441)	1.776 (0.931 to 3.386)	1.619 (0.842 to 3.114)
92–	129	23.2	2.249 (1.198 to 4.220)	2.242 (1.193 to 4.216)	2.277 (1.195 to 4.339)	1.988 (1.024 to 3.861)
97–	125	22.5	2.343 (1.247 to 4.404)	2.241 (1.189 to 4.226)	2.570 (1.343 to 4.918)	2.189 (1.118 to 4.285)
WHR						
<0.87	136	24.5	Reference	Reference	Reference	Reference
0.87–	142	25.6	1.190 (0.616 to 2.301)	1.173 (0.606 to 2.271)	1.223 (0.620 to 2.410)	1.088 (0.546 to 2.168)
0.91–	137	24.7	1.877 (1.004 to 3.509)	1.790 (0.954 to 3.360)	1.837 (0.967 to 3.490)	1.581 (0.821 to 3.047)
0.94–	140	25.2	1.899 (1.019 to 3.539)	1.806 (0.965 to 3.378)	2.145 (1.126 to 4.085)	1.873 (0.968 to 3.623)
WSR						
<0.51	141	25.4	Reference	Reference	Reference	Reference
0.51–	136	24.5	1.485 (0.755 to 2.921)	1.449 (0.735 to 2.857)	1.495 (0.745 to 3.001)	1.297 (0.637 to 2.640)
0.54–	134	24.1	1.673 (0.858 to 3.262)	1.618 (0.827 to 3.162)	1.738 (0.875 to 3.452)	1.581 (0.789 to 3.167)
0.57–	144	25.9	3.003 (1.614 to 5.591)	2.782 (1.482 to 5.224)	3.183 (1.661 to 6.101)	2.572 (1.301 to 5.083)

Model 1: unadjusted; model 2: adjusted for age; model 3: adjusted for age, smoking, alcohol drinking and regular exercise; model 4: adjusted for age, smoking, alcohol drinking, regular exercise, hypertension, TG and TC.
BMI, body mass index; T2DM, type 2 diabetes mellitus; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-to-hip ratio; WSR, waist-to-stature ratio.

Table 4 OR and 95% CI for the presence of T2DM according to quartiles of anthropometric indicators for women

Variable	n	%	Model 1	Model 2	Model 3	Model 4
BMI (kg/m^2)						
<22.96	296	25.5	Reference	Reference	Reference	Reference
22.96–	296	25.5	2.240 (1.322 to 3.797)	2.233 (1.317 to 3.785)	2.220 (1.307 to 3.770)	1.936 (1.130 to 3.316)
25.30–	288	24.8	2.374 (1.402 to 4.019)	2.370 (1.400 to 4.012)	2.396 (1.413 to 4.063)	2.006 (1.169 to 3.442)
27.77–	279	24.1	3.183 (1.905 to 5.319)	3.161 (1.890 to 5.288)	3.230 (1.926 to 5.415)	2.764 (1.622 to 4.712)
WC (cm)						
<81	334	28.8	Reference	Reference	Reference	Reference
81–	305	26.3	1.377 (0.844 to 2.246)	1.399 (0.855 to 2.289)	1.421 (0.867 to 2.329)	1.277 (0.771 to 2.117)
88–	262	22.6	1.994 (1.236 to 3.217)	2.043 (1.258 to 3.318)	2.056 (1.264 to 3.345)	1.808 (1.094 to 2.988)
94–	258	22.3	2.587 (1.626 to 4.115)	2.697 (1.661 to 4.378)	2.755 (1.693 to 4.484)	2.407 (1.455 to 3.985)
WHR						
<0.83	301	26.0	Reference	Reference	Reference	Reference
0.83–	295	25.5	1.685 (1.009 to 2.813)	1.710 (1.022 to 2.861)	1.705 (1.018 to 2.855)	1.589 (0.942 to 2.680)
0.86–	283	24.4	2.178 (1.321 to 3.589)	2.255 (1.356 to 3.751)	2.305 (1.383 to 3.842)	1.998 (1.187 to 3.362)
0.91–	280	24.2	2.651 (1.625 to 4.327)	2.801 (1.677 to 4.679)	2.816 (1.685 to 4.706)	2.500 (1.484 to 4.211)
WSR						
<0.51	302	26.1	Reference	Reference	Reference	Reference
0.51–	299	25.8	1.581 (0.985 to 2.609)	1.620 (0.978 to 2.681)	1.606 (0.969 to 2.661)	1.384 (0.823 to 2.362)
0.56–	285	24.6	1.765 (1.073 to 2.904)	1.843 (1.109 to 3.062)	1.846 (1.110 to 3.070)	1.595 (0.945 to 2.693)
0.60–	273	23.6	2.652 (1.644 to 4.277)	2.862 (1.720 to 4.763)	2.891 (1.733 to 4.822)	2.452 (1.447 to 4.155)

Model 1: unadjusted; model 2: adjusted for age; model 3: adjusted for age, smoking, alcohol drinking and regular exercise; model 4: adjusted for age, smoking, alcohol drinking, regular exercise, hypertension, TG and TC.
BMI. body mass index; T2DM, type 2 diabetes mellitus; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-to-hip ratio; WSR, waist-to-stature ratio.

Table 5 AUC and 95% CI of the prediction of T2DM according to anthropometric indicators by gender

Variable	Model 1	Model 2	Model 3	Model 4
Men				
BMI (kg/m^2)	0.552 (0.493 to 0.611)	0.586 (0.523 to 0.649)	0.663 (0.607 to 0.719)	0.692 (0.636 to 0.747)
WC (cm)	0.584 (0.526 to 0.642)	0.610 (0.551 to 0.669)	0.670 (0.615 to 0.725)	0.694 (0.639 to 0.749)
WHR	0.572 (0.513 to 0.631)	0.596 (0.539 to 0.652)	0.659 (0.604 to 0.713)	0.690 (0.636 to 0.744)
WSR	0.608 (0.549 to 0.668)	0.614 (0.554 to 0.675)	0.679 (0.622 to 0.735)	0.703 (0.648 to 0.758)
Women				
BMI (kg/m^2)	0.599 (0.555 to 0.642)	0.604 (0.560 to 0.648)	0.618 (0.575 to 0.661)	0.669 (0.627 to 0.711)
WC (cm)	0.600 (0.555 to 0.644)	0.602 (0.557 to 0.647)	0.609 (0.565 to 0.654)	0.662 (0.622 to 0.703)
WHR	0.594 (0.550 to 0.638)	0.596 (0.550 to 0.641)	0.611 (0.567 to 0.656)	0.668 (0.627 to 0.709)
WSR	0.592 (0.547 to 0.637)	0.594 (0.549 to 0.640)	0.607 (0.563 to 0.652)	0.663 (0.622 to 0.704)

Model 1: unadjusted; model 2: adjusted for age; model 3: adjusted for age, smoking, alcohol drinking and regular exercise; model 4: adjusted for age, smoking, alcohol drinking, regular exercise, hypertension, TG and TC.
AUC, areas under the receiver operating characteristic curves; BMI, body mass index; T2DM, type 2 diabetes mellitus; TC, total cholesterol; TG, triglyceride; WC, waist circumference; WHR, waist-to-hip ratio; WSR, waist-to-stature ratio.

were 0.604 (0.560 to 0.648), 0.618 (0.575 to 0.661), 0.669 (0.627 to 0.711) in models 2, 3 and 4, respectively, and was larger than that for the WC, WHR and WSR.

DISCUSSION

The prevalence of T2DM has been increasing and the current situation is especially serious in Asia and China.[24 25] The prevalence of T2DM was 19.3% for men and 15.3% for women in adults ≥50 years in our study. This prevalence was higher than that of 11.6% for all of China,[26] 12.7% for Harbin,[27] 5.5% for Guangzhou,[28] 6.7% for Shanghai,[29] 5.3% for Haikou[30] and 7.6% in the Three Gorges Reservoir Region.[31] T2DM prevalence increased with age, in men more than women, in urban more than rural areas and in the north more than the south of China.[4 26] Our findings differed from those of the above study because we studied an older group in northern and urban locations. A more thorough investigation is, therefore, needed that examines many age groups and geographical regions.

The proportion of patients with undiagnosed T2DM declined with age.[3 32] The proportion of undiagnosed patients with T2DM was 32.7% in our study, which was lower than the 60% found in a nationwide study of China.[4] The high proportion of patients with undiagnosed T2DM will increase the long-term cost of the disease in China.[33] Early intervention can prevent or delay T2DM onset.[34 35] Routine screening for undiagnosed T2DM is especially important and should be implemented as soon as possible in China. Owing to the economic and demographic situation of China, simple, economical and convenient indicators should be found to identify the population that is at a high risk of developing T2DM to reduce costs.

Anthropometric indices of the relationship between obesity and T2DM would provide effective screening for T2DM.[36] However, the best index (BMI, WC, WHR or WSR) for indicating the relationship between obesity and T2DM is unknown and the conclusions are not uniform. The relationship between obesity and T2DM may differ according to age, sex or race,[37] and according to which indicator is used to best represent the relationship between obesity and T2DM. Thus, in this study, we examined the relationship between obesity and T2DM among people aged ≥50 years in Jinan, China. Age, height, weight, WC, WHR, WSR, DBP, FPG, TG, TC measurements and the prevalence of obesity, hypertension, smoking and alcohol drinking differed significantly according to gender, suggesting that gender is a strong confounder. Subgroup analyses were conducted in men and women to show and compare the relationships between obesity and T2DM. Our final sample included more women than men; this might have been because the women were more willing to comply with the requirements of the survey and the physical examination than men.

According to our results, the best indicator for the relationship between obesity and T2DM was WSR for men and BMI for women. Most studies in China, including two studies from northeast China,[38 39] a study involving three cities of northern China and four cities of southern China,[40] and another study from the China National Nutrition and Health Survey,[36] confirmed that WSR was better than BMI, WC and WHR. The above results were also found in other Asian countries, such as Iran,[41] Korea[42] and Japan.[43] Our study included an older study population and a study from Changchun in northeast China included adults aged ≥40 years. However, other studies included adults aged ≥20 years. The results for the men were the same as those in previous studies; however, BMI was the best indicator for the relationship between obesity and T2DM for the women in our study. Our results for the women differed from those of previous studies, possibly for the following reasons. First, the average age of the subjects in our study was approximately 63 years and age-related declines in muscle and increases in adipose tissues have been demonstrated;[44] second, some studies found that WC was greater in men than women,[45 46] which

suggested that fat in men was focused more on the waist rather than throughout the body, whereas fat tissue in the women was spread throughout the body. The above confirmed that older women have more peripheral fat than men;[47] this may explain why BMI is better than the other indicators in elderly women.

T2DM screening and prediction are both important in view of the serious situation. The best index of obesity adopted in a screening model for T2DM differs from that in a prediction model. This means we must be aware that the best predictive indexes are from prospective cohort studies, whereas the best screening indexes are from cross-sectional studies. Thus a cross-sectional study was performed to determine the best obesity indicator for T2DM screening in this study. In addition, the relationship between obesity and T2DM varies with age, sex and ethnicity.[37] T2DM screening is important for adults aged ≥50 years because they have higher risks. No study has yet focused on the relationship between obesity and T2DM for Chinese people aged ≥50 years. In our study, the obesity indexes used for T2DM screening by sex for Chinese adults ≥50 years are proposed. This conclusion remains to be confirmed in further cross-sectional studies by age group.

Our investigation had several limitations. First, our study had a cross-sectional design, which can be used to explore the associations between obesity and T2DM but cannot be used to explore causations. However, it is suitable for identifying populations that are at a high risk of T2DM. A prospective cohort study would be useful to determine the predictive indicators of T2DM. Second, about half of the sample in this study did not take part in the physical examination, which might have created a selection bias.

In conclusion, WSR and BMI were the best indicators of the relationship between obesity and T2DM for men and women, respectively, among adults aged ≥50 years in Jinan, China. The FPG of adults aged ≥50 years should be monitored regularly to identify patients with T2DM using the WSR for men and BMI for women.

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