Original Article

BMI, WC, WHtR, VFI and BFI: Which Indictor is the Most Efficient Screening Index on Type 2 Diabetes in Chinese Community Population*

MI Sheng Quan[1], YIN Peng[2], HU Nan[2], LI Jian Hong[2], CHEN Xiao Rong[2], CHEN Bo[2], YAN Liu Xia[2], and ZHAO Wen Hua[3,#]

1. College of Arts and Science of Beijing Union University, Beijing 100191, China; 2. National Center for Chronic and Non-communicable Disease Control and Prevention of China CDC, Beijing 100053, China; 3.Chinese Center for Disease Control and Prevention, Beijing 102206, China

Abstract

Objective Obesity is a major risk factor for type 2 diabetes, many indexes can be used to describes obesity and predict diabetes. This research attempts to identify the best indicator of obesity to screening diabetes in Chinese population.

Methods A cross-sectional data of 8121 subjects aged 35-60 years were included in this research belongs to the Diabetes Appropriate Technology Intervention Study. Anthropometric indicators including body weight, height, waist circumferences (WC), body fat index (BFI) and visceral fat index (VFI) and blood biochemical indicators after an overnight fast [fasting blood glucose, total cholesterol, high-density lipoprotein (HDL) cholesterol, and triacylglycerol] were measured. BMI (body mass index) and Weight to Height Ratio was calculated.

Results Subjects with obesity had a higher risk of physician diagnosed diabetes (OR=2.50, 95% CI 1.83-3.43), new diagnosed diabetes (OR=4.23, 95% CI 2.91-6.15) and pre-diabetes (OR=1.75, 95% CI 1.31-2.34) compared to those with normal Body mass index (BMI). There was a significant trend of increased risk of all diabetes status with increased waist circumference (WC). The waist-to-height ratio (WHtR) yielded the most significant association with new diagnosed diabetes and physician diagnosed diabetes than other indices.

Conclusion Central obesity is significantly correlated with diabetes. VFI was most correlated with pre-diabetes while WHtR is an efficient screening index than BMI and WC in Chinese community diabetes screening.

Key words: Obesity; Diabetes; BMI; Waist Circumference; Waist-to-height ratio

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INTRODUCTION

Obesity is a major risk factor for type 2 diabetes[1]. Body mass index (BMI) is commonly used to identify overweight and obesity for its strong relationship with diabetes[2-3]. However, many central obesity indices including waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-stature ratio (WSR) were found more closely correlated with the incidence of diabetes than BMI, mainly based on cross-sectional data[4-6]. Some population-based prospective studies

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#Correspondence should be addressed to ZHAO Wen Hua. Ph. D, Professor. Tel: 86-010-58900234. E-mail: whzhao@ilsichina.org

Biographical note of the first author: MI Sheng Quan, Ph. D, male, born in 1975, majoring in nutrition epidemiology.

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have shown that BMI and central obesity indicators were equally well associated with the incidence of diabetes[6]. Other studies indicated that waist-to-height ratio (WHtR) or WHR is a better anthropometric index than BMI and WC[7-9]. It is recognized that which obesity index best explains prevalence differences in type 2 diabetes depend on different population and differences in diabetes prevalence between these populations cannot always be attributed to a particular measure of obesity[7]. There is very little information in Chinese population exploring the association of obesity indicators with diabetes.

As diabetes has become a big public health problem in China and the potential number of diabetes patients in the community could be substantial, it is important to identify the population with high risk of diabetes using simple measurements. We compared the correlation of common obesity related indicators including BMI, WC, Body Fat Index (BFI), Visceral Fat Index (VFI) and WHtR with diabetes status in a large community based study in China.

METHODS

Study Population

The Diabetes Appropriate Technology Intervention Study was a community-based study conducted in Beijing municipality and Zhejiang province in China from 2009 to 2010 to develop appropriate intervention technology for diabetes in the community in Chinese population. Two rural villages and two urban neighborhood committees were selected from each study site. Villages and urban neighborhood committees are the equivalent administrative unit in China. Village is for rural areas and neighborhood committee is for urban areas. All residents aged 35-60 years from the village and neighborhood committee were informed and encouraged to participate in the study. We only included those who were ambulatory without cancer or any acute infectious diseases. All participants were invited to a local community health center to receive a face to face questionnaire interview, physical measurement as well as the collection of fasting blood sample. All participants signed an informed consent and the protocol was approved by China CDC Ethics Committee.

Data Collection

A detailed questionnaire was used to collect information on demographic characteristics, socio-economic status, disease history, lifestyle/behaviors information including food consumption frequency and physical activity by face to face interview.

Anthropometric Variables

Height, weight and waist circumference were measured by trained local staffs according to standard protocol. BMI was calculated as weight in kilograms divided by the square of height in meters (kg/m^2). Waist to height ratio was calculated as WC divided by height in centimeters. Body Fat Index (BFI) and visceral Fat Index (VFI) were obtained by OMRON's total body monitoring scale (HBF-500) with Bioelectrical Impedance (BI) method. All anthropometric indicators were obtained before blood sample was collected.

Glucose and Lipid Profiles

Blood samples were collected in the morning after an 8-12 h fast. Fasting blood glucose, total cholesterol, high-density lipoprotein (HDL) cholesterol, and triacylglycerol were determined in local laboratory centers after standardized by blind samples. If participants without diabetes history had a plasma glucose ≥6.10 mmol/L, a standard oral glucose tolerance test (OGTT) was administered after two days. All the fasting blood glucose and the 2 h postprandial blood glucose were measured in 2 h after collection.

Obesity Definition

The BMI threshold for obesity by Chinese Obesity Working Group was: 18.5≤BMI<24.0 kg/m^2 as normal, 24.0≤BMI<28.0 kg/m^2 as overweight and BMI≥28.0 as obesity[9-10]. Central obesity was defined as WC>85 cm in males and WC>80 cm in females based on the cut-off recommended by Chinese Obesity Working Group[12]. Based on the instructions of OMRON's total body monitoring scale, we used cut-offs 10, 15, 19 for VFI classification and 24, 29, 35 for BFI classification respectively.

Diabetes and Pre-diabetes Population Definition

Diabetes patients were defined as participants who reported a previously physician diagnosed diabetes history. New diagnosed diabetes patients were defined if participants reported no diabetes history but with fasting plasma glucose ≥7.0 mmol/L or 2 h 75 g anhydrous plasma glucose ≥11.1 mmol/L. Pre-diabetes was defined as those without diabetes

history but with fasting plasma glucose 6.11-6.99 mmol/L or 2 h 75 g anhydrous plasma glucose 7.77-11.1 mmol/L.

Statistical Analysis

Data analysis was performed with SPSS for Windows (SPSS 17.0). The Chi-square was employed to compare the difference of categorical variables. Linear regression was used to analyze the association of BMI, waist circumference, waist-to-height ratio with diabetes status. To test the association of diabetes status with each obesity index (i.e. BMI, WC, VFI, BFI, and WHtR), the multivariate logistic regression was conducted to produce the odds ratios and 95% confidence intervals (95% CI) controlling for age and gender.

RESULTS

Characteristics of the Study Population

Of 8121 subjects who agreed to participate in the study, 7171 (88.3%) completed questionnaire interviews, physical measurements and biochemical test with valid data. Among the 7171 participants, 3108 (43.3%) were males and 3973 (55.4%) were in the rural.

The Prevalence of Diabetes and Obesity

The prevalence rates of overweight and obesity in the study population are shown in Table 1. According to the Chinese definition, the overall prevalence of overweight and obesity was 38.2% and 20.0% respectively. The percentage of subjects with obesity accounted for 29.9%, 21.7%, and 14.9% in age group 55-60, 45-54, and 35-44 respectively. It yielded the same pattern in both males and females.

Overall, 549 (7.7%) subjects were diabetes patients including new diagnosed diabetes and previously diagnosed diabetes. No statistically significant difference was found for the diabetes prevalence between rural and urban populations (7.4% *vs*. 7.9%, *P*=0.40). The undiagnosed diabetes ratio was 42.6% (234 new-diagnosed diabetes of 549 patients) with no difference between males and females (*P*=0.61). The overall prevalence of pre-diabetes was 5.4% (385/7171). The diabetes status of the study population by age and gender are shown in Table 2.

Table 1. Prevalence of Overweight and Obesity in the Study Population (*n*/%)

Age Group	Male			Female			Total		
	N	Overweight	Obesity	*N*	Overweight	Obesity	*N*	Overweight	Obesity
35-44	1184	457 (38.6)	204 (17.2)	1618	513 (31.7)	214 (13.2)	2802	970 (34.6)	418 (14.9)
45-54	1326	560 (42.2)	264 (19.9)	1704	658 (38.6)	394 (23.1)	3030	1218 (40.2)	658 (21.7)
55-65	598	258 (43.1)	179 (29.9)	741	295 (39.8)	179 (24.2)	1339	553 (41.3)	358 (26.7)
Total	3108	1275 (41.0)	647 (20.8)	4063	1466 (36.1)	787 (19.4)	7171	2741 (38.2)	1434 (20.0)

Note. Overweight: 24≤BMI<28, Obesity: BMI≥28.0.

Table 2. Diabetes Status of the Study Population by Age and Sex (*n*)

Age	Male				Female				Total
	Normal	New-diagnosed DM[a]	DM[b]	Pre-DM[c]	Normal	New-diagnosed DM	DM	Pre-DM	
35-44	1075	31	27	51	1514	33	22	49	2802
45-54	1089	50	88	99	1489	56	74	85	3030
55-65	477	31	43	47	593	33	61	54	1339
Total	2641	112	158	197	3596	122	157	188	7171

Note. a: New- diagnosed DM: No diabetes history but with fasting plasma glucose ≥7.0 mmol/L or 2 h 75 g anhydrous plasma glucose ≥11.1 mmol/L. b: DM: Reported a previously physician diagnosed diabetes history. c: Pre-DM: Without diabetes history but with fasting plasma glucose 6.11-6.99 mmol/L or 2 h 75 g anhydrous plasma glucose 7.77-11.1 mmol/L.

Relation of Obesity Indices with Diabetes

The average waist circumference in males exceeds that in females (87.0±9.9 cm *vs.* 81.6±9.6 cm, *P*<0.01). As shown in Table 3, a statistically significant increase of WC with age was observed in females (79.5±9.0 cm for 35-44, 82.7±9.6 cm for 45-54, 83.9±10.4 cm for 55-65; *r*=0.18, *P*<0.01), but not in males. The average VFI in males was 10.2, 12.0, and 12.2 for age 35-44, 45-54, and 55-60 years respectively while the average VFI in females was 6.4, 8.3, and 9.1 in the 3 age groups. The correlation coefficients of age with VFI was 0.18 (*P*<0.01) with a much stronger correlation found in females (*r*=0.30, *P*<0.01).

As shown in Table 4, all the obesity related indicators showed significant association with diabetes. Using subjects with normal BMI (18.5≤BMI<24) as reference group, subjects with obesity (BMI≥28) had a higher risk of physician diagnosed diabetes [OR=2.50, 95% CI (1.83-3.43)], new diagnosed diabetes [OR=4.23, 95% CI (2.91-6.15)] and pre-DM [OR=1.75, 95% CI (1.31-2.34)].

Table 3. Anthropometric Characteristics of the Study Population by Age and Sex

Age	Male			Female		
	35-44 (*n*=1184)	45-54 (*n*=1326)	55-65 (*n*=598)	35-44 (*n*=1618)	45-54 (*n*=1704)	55-65 (*n*=741)
Height (cm)	168.6±6.2	167.6±6.6	166.8±5.9	157.7±5.6	156.8±5.6	155.5±5.3
Weight (kg)	70.5±11.6	70.9±10.9	69.8±10.8	59.8±9.6	62.4±9.8	61.9±10.4
BMI	24.7±3.6	25.2±3.9	25.0±3.4	24.0±3.4	25.4±3.7	25.6±3.7
WC (cm)	86.5±9.9	87.6±9.8	86.7±10.4	79.5±9.0	82.7±9.6	83.9±10.4
VFI	10.2±4.5	12.0±6.1	12.2±5.0	6.4±4.4	8.3±5.1	9.1±5.8
BFI	23.3±5.0	24.6±5.2	25.2±4.9	30.9±4.1	33.2±4.2	34.7±4.0
WHtR	0.513±0.056	0.523±0.059	0.520±0.061	0.504±0.056	0.528±0.061	0.540±0.067

Table 4. Multivariate Logistic Regression Analysis Adjusted for Sex and Age in Subjects with Different Diabetes Status

Indicators		*N*	%	Pre-DM[a]		New- diagnosed DM[b]		DM[c]	
				OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
BMI	<18.5	132	1.8	1.23 (0.53-2.85)	0.636	1.04 (0.25-4.34)	0.958	0.59 (0.14-2.45)	0.469
	18.5-24	2937	41.0	reference		reference		reference	
	24-28	2741	38.2	1.78 (1.40-2.27)	<0.001	2.71 (1.89-3.86)	<0.001	1.96 (1.48-2.60)	<0.001
	≥28	1361	19.0	1.75 (1.31-2.34)	<0.001	4.23 (2.91-6.15)	<0.001	2.50 (1.83-3.43)	<0.001
WC	male:<75, female:<70	806	11.2	reference		reference		reference	
	male:75-85, female:70-80	2309	32.2	1.04 (0.69-1.56)	0.857	2.38 (1.00-5.56)	0.49	2.84 (1.46-5.53)	0.002
	male:85-95, female:80-90	2592	36.2	1.66 (1.13-2.45)	0.009	5.57 (2.43-12.76)	<0.001	4.13 (2.15-7.93)	<0.001
	male:≥95, female:≥90	1462	20.4	1.77 (1.18-2.66)	0.006	9.15 (3.98-21.03)	<0.001	6.26 (3.25-12.09)	<0.001
VFI	<10	4150	58.3	reference		reference		reference	
	10-15	2063	29.0	1.65 (1.29-2.10)	<0.001	2.68 (1.94-3.72)	<0.001	1.88 (1.44-2.46)	<0.001
	15-19	729	10.2	2.16 (1.57-2.97)	<0.001	4.37 (2.95-6.48)	<0.001	1.53 (1.04-2.27)	0.033
	≥19	181	2.5	1.17 (0.58-2.36)	0.666	5.21 (2.97-9.46)	<0.001	2.54 (1.44-4.47)	0.001
BFI	<24	1518	21.3	reference		reference		reference	
	24-29	1964	27.6	1.39 (1.02-1.90)	0.038	2.21 (1.41-3.45)	0.001	1.22 (0.86-1.73)	0.265
	29-35	2369	33.3	1.87 (1.30-2.70)	0.001	3.42 (2.08-5.62)	<0.001	1.76 (1.18-2.64)	0.006
	≥35	1272	17.9	3.17 (2.06-4.88)	<0.001	6.41 (3.61-11.38)	<0.001	2.92 (1.82-4.68)	<0.001
WHtR	<0.445	761	10.6	reference		reference		reference	
	0.445-0.525	3197	44.6	1.46 (0.95-2.25)	0.088	3.15 (1.26-7.87)	0.014	3.52 (1.71-7.25)	<0.001
	0.525-0.625	2871	40.1	2.30 (1.50-3.52)	<0.001	7.70 (3.14-18.89)	<0.001	5.59 (2.73-11.44)	<0.001
	≥0.625	337	4.7	1.06 (0.51-2.19)	0.880	16.01(6.15-41.71)	<0.001	8.61 (3.88-19.08)	<0.001

Note. a: Pre-DM: Without diabetes history but with fasting plasma glucose 6.11-6.99 mmol/L or 2 h 75 g anhydrous plasma glucose 7.77-11.1 mmol/L. b: DM: Reported a previously physician diagnosed diabetes history. c: New- diagnosed DM: No diabetes history but with fasting plasma glucose ≥7.0 mmol/L or 2 h 75 g anhydrous plasma glucose ≥11.1 mmol/L.

There was a significant trend of increased risk of all diabetes status with increased WC. The OR reached 9.15, 95% CI (3.98-21.03) for new diagnosed diabetes in the central obesity group (WC>95 cm in males and >90 cm in females). Similar to WC, the VFI increased the risk of new- diagnosed DM [OR 5.21, 95% CI (2.97-9.46) for highest VFI] and DM [OR 2.54, 95% CI (1.44-4.47) for highest VFI]. However, there was no association between highest VFI (>19) and pre-diabetes while the association was significant in those with VFI 15-19. TC and TG had the same trends as VFI (data not shown). Significant increasing trend was observed between BFI and higher risk of all diabetes status with magnitude highest in new diagnosed diabetes and lowest in physician diagnosed diabetes.

The WHtR is the most significant indicator with new-diagnosed DM and physician diagnosed diabetes than other indexes. Compared with lowest WHtR, those with WHtR 0.445-0.525 had a 3.15 times risk of new- diagnosed DM and those with highest WHtR had 16 times risk of new- diagnosed DM.

DISCUSSION

This study showed that the overall prevalence of type 2 diabetes was 7.7% for Chinese population aged 35-60 years. There have been a number of studies estimating the prevalence of diabetes in China using different methods. The Chinese National Nutrition and Health Survey in 2002 reported the prevalence of diabetes was 4.29% for Chinese population aged 45-59 years[13]. Yang et al. reported that the prevalence of total diabetes (including both previously diagnosed diabetes and previously undiagnosed diabetes) among Chinese aged 20 years and over was 9.7% based on a most recent study conducted in 14 provinces and municipalities in China. In our study, 42.6% of diabetes populations were undiagnosed, which is about 3.3% in our total population. This is similar with a study carried out in Qingdao with undiagnosed rate 4.6% in men and 3.3% in women[14], but lower than Yang's study (6.5%). The highest undiagnosed rate (9.5%) was found in a cross-sectional study done in Fujian, southeast China[15]. The prevalence rate of pre-diabetes was 5.4% in our study population, much lower than the estimation of other studies in Chinese population[16].

The diabetes prevalence was known to be higher in urban areas than in rural areas. However, with the rapid economic development in rural area, the diabetes prevalence increased dramatically and the gap between rural and urban narrowed down gradually. Both of the two fields in our study had relatively better health care infrastructure compared to most of the areas in China, the residents in these two areas had high clinical consultation rate. This may imply that the problem of undiagnosis of diabetes could be more serious at national level.

As diabetes has become a major public health problem in China, assessment of diabetes risks using simple measurements is therefore urgently needed in the community for Chinese population. In order to identify the best index as a screening tool for diabetes risk, we used a number of obesity indices in this study, including BMI, WC, VFI, and BFI. The obesity indices yielded different level of correlation in different diabetes period. In pre-diabetes population, the VFI is more sensitive than other obesity indices. For new diagnosed diabetes, BMI correlated more than TG and TC, but less than WC, VFI, and BFI. WHtR correlated the most with new diagnosed diabetes.

According television news coverage of obesity in China from 1982-2009, obesity showed an incremental trend as the economy grew[17]. Obesity was mostly depicted as an individual problem in adult as well as in children[17-18]. Before 1960's, central obesity has been identified more important than peripheral obesity in relation to diabetes[19]. In Chinese population, central obesity is more related to DM and impaired fasting glucose (IFG) than is overall obesity and both WC and WHR are equally able to identify DM[3]. WC can be a moderate predictor for visceral fat and provides a feasible measurement to estimate glucose metabolic risks[20]. This study reconfirmed that VFI is most correlated with abdominal adipose tissue, and has a significant correlation with diabetes. Waist circumference is considered the best surrogate measure of abdominal visceral fat, which is typical for epidemiological studies[21]. Waist circumference was more consistently associated with the prevalence of diagnosed diabetes than BMI[4]. But WC may underestimate the relative amount of abdominal fat in short subjects and overestimate it in tall subjects and consequently be misleading[22]. WHtR combined WC with height which is more commonly and more conveniently measured than hip circumference. WHtR remains good to present the abdominal visceral fat of WC and eliminates the body size difference. It can improve the ability of waist

circumference to predict diabetes. But WHtR is less common than waist to statures ratio and waist to hip ratio in epidemiological studies. Many documents indicated that the area under the curve (AUC) for waist-to-height ratio tended to be greater than that for waist circumference[7,23]. This is similar as Lorenzo's report that WHtR can improve the ability of waist circumference to identify Mexican-origin and Spanish women with diabetes[7]. In some other studies, WHtR presented better than BMI and WC in predicting diabetes[24], even in two decades before[25].

Although we obtained consistent results with other reports using a large community based setting, our study has some limitations. First, our study participants were selected from a sample of relatively developed areas in China. Our results may not be representative of the whole population and may underestimate the prevalence and under diagnosis rate of diabetes. Also, we only included participants aged 35-60 years old. The prevalence of diabetes is therefore relatively underestimated due to the absence of elderly people who are at higher risk of diabetes. Second, VFI in this study was based on the Bioelectrical Impedance (BI) method which sends a weak electrical current through the body to determine the amount of the fat and skeletal muscle tissue. This is not as accurate and reproducible as computed tomography (CT) or MIR in assessing abdominal fat[26]. BI has poor ability in distinguishing the distribution of total body water into its intracellular and extracellular compartments and total body water and extracellular water are greater in obese individuals than normal-weight individuals[27]. However, the VFI was conducted after overweight fasting before eating food and water in our study. Second, the cross-sectional nature of this study deterred the interpretation of prediction effect of various obesity indices and diabetes status. It still needs to be further explored and verified in longitudinal studies.

In summary, the prevalence of diabetes is high in this population and the undiagnosis of diabetes is common. Central obesity is significantly correlated with diabetes. Visceral fat index is most correlated with pre-diabetes while WHtR is an efficient index than BMI and WC in Chinese community diabetes screening.

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