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PAPER

Body fat distribution and risk of diabetes among Chinese women

AD Rosenthal[1], F Jin[2], X-O Shu[1]*, G Yang[1], TA Elasy[3], W-H Chow[4], B-T Ji[4], H-X Xu[2], Q Li[2], Y-T Gao[2] and W Zheng[1]

[1]*Department of Medicine and Vanderbilt-Ingram Cancer Center, Vanderbilt University, Nashville, TN, USA;* [2]*Department of Epidemiology, Shanghai Cancer Institute, Shanghai, China;* [3]*Diabetes Research and Treatment Center, Vanderbilt University, Nashville, TN USA; and* [4]*Division of Cancer Epidemiology and Genetics, National Cancer Institute, Bethesda, MD, USA*

OBJECTIVE: To assess the relationship between measures of central and overall obesity and risk of diabetes.
DESIGN: Nested case–control study.
SETTING: Shanghai, China.
PARTICIPANTS: A total of 57 130 women were screened for diabetes at enrollment for the Shanghai Women's Health Study (SWHS), a population-based cohort study of Chinese women aged 40–70 y. In this study, 345 women diagnosed with diabetes and 2760 age-matched controls (eight controls per case), randomly selected from women who tested negative for urine glucose, were included.
RESULTS: Risk of diabetes increased significantly with increasing levels of obesity, particularly with measures of central obesity. Compared to those in the lowest quartile, women in the highest quartile of body mass index (BMI) ($\geq$26.57) and waist to hip ratio (WHR) ($\geq$0.855) had a 2.57-fold (95% CI 1.75–3.77) and a 6.05-fold (95% CI 4.05–9.04) increased risk of diabetes, respectively. The risk of diabetes was elevated with increasing WHR at all levels of BMI, while the positive association between BMI and diabetes was observed primarily among women with a low WHR. However, test for multiplicative interaction was not statistically significant.
CONCLUSIONS: Our data indicated that central obesity is a stronger risk factor for diabetes than overall obesity, suggesting that WHR may be a better indicator of risk of diabetes than BMI among Chinese women.
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Introduction

Estimates from the World Health Organization predict that by the year 2025, 300 million people worldwide will be diagnosed with diabetes.[1] The Asian/Pacific region, accounting for 46 percent of the global burden of diabetes, includes the largest population of people diagnosed with diabetes in the world.[2] Studies among the Chinese have demonstrated an increase in the prevalence of diabetes during the past 10 years, particularly in urban areas such as Shanghai.[3–9] The increased prevalence of type II diabetes in these and other Asian populations can be attributed, at least partially, to increases in obesity.[2,5–7,10]

Body mass index (BMI) and waist to hip ratio (WHR) are the two anthropometric measurements most frequently used to assess obesity and central obesity. Although epidemiological studies have demonstrated that both BMI and WHR are powerful predictors of type II diabetes, the relative contribution of each to an individual's risk remains unclear.[11–19] Further complicating this issue, quantitative definitions used to indicate obesity differ among studies and among gender and ethnic groups. The World Health Organization currently defines overweight as a BMI of 25–29.9 kg/m^2 and obese as a BMI $\geq$30 kg/m^2.[20] However, compared to Caucasians, Chinese people appear to have a higher body fat percentage given the same BMI.[5] Specifically, 32 percent body fat, which is considered obese by the WHO, corresponded to a BMI of only 21.2 kg/m^2 in Chinese women, which is considered

*Correspondence: Dr XO Shu, Center for Health Services Research, 6009 Medical Center East, Vanderbilt University, 1215 21st Ave South, Nashville TN, 37232.
E-mail: Xiao-ou.Shu@Vanderbilt.edu
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nearly optimal by US standards.[21] In addition, there is growing evidence, particularly among Asian and female populations, that central obesity may be a more consistent predictor of glucose intolerance and type II diabetes than overall obesity.[11–14,17,18,22–25] Thus, it is imperative to investigate the utility of BMI and WHR in predicting risk of diabetes in Chinese and other Asian women.

Furthermore, given the strong correlation between central and overall obesity, and the high prevalence of obesity among the US population, it is difficult to examine the effect of central fat distribution on risk of diabetes among normal-weight women in the US[26] Traditionally, Chinese women have a low rate of obesity, providing a unique opportunity to examine the effects of central adiposity on risk of diabetes among nonobese women.[5] We examined the association between anthropometric measurements and risk of diabetes among a subset of participants who were screened for diabetes at enrollment for the Shanghai Women's Health Study (SWHS).

Methods

The SWHS is a population-based prospective cohort study conducted in seven urban communities in Shanghai, China. All eligible women ($n = 81\,170$), who were aged 40–70 y and resided in these communities between March 1997 and May 2000, were approached for the study and 75 221 women were enrolled, yielding a participation rate of 92.7%. After further exclusion of 278 women who were later found to be younger than 40 or older than 70 y at the time of interview, 74 443 women remained for the SWHS. The major reasons for nonresponse were refusal to participate (3.0%), absent during enrollment period (2.6%), and other miscellaneous reasons (ie, health, hearing, and speaking problems; 1.6%). For 56 832 (75.7%) women who donated a spot urine sample at enrollment, a semiquantitative urinalysis dipstick assay was performed to screen for diabetes. Of the 1254 women who tested positive for urine glucose (>trace), 566 had no prior history of diabetes. Among the later, 345 women were subsequently diagnosed with diabetes using a fasting blood glucose test, an oral glucose tolerance test, or both. The WHO guidelines for fasting blood glucose testing (≥ 7 mg/dl) and oral glucose tolerance testing (≥ 11.1 mg/dl) were used to confirm cases of diabetes. A total of 228 of these women were tested at the study's designated testing facilities, while the remainder of subjects had their tests performed at the their primary care hospital. The 345 subjects with confirmed diabetes comprised the case group for the study. Controls were randomly selected from study participants, who tested negative for urine glucose, had no prior history of diabetes, and were individually matched to the index cases by age (within 1 y) at a ratio of eight controls per case.

Information on usual dietary intake during the past year, personal habit, physical development, occupation history, and medical history were elicited by trained interviewers using a structured questionnaire during in-person interviews. In order to enhance the quality of interview data, interviews were tape recorded and selectively monitored by quality control staff.

Study participants were measured for weight, standing and sitting height, and waist and hip circumferences by trained interviewers according to a standard protocol at the baseline survey. Waist circumferences were measured at 2.5 cm above the navel and hip circumferences at the level of maximum width of the buttocks. All measurements were taken twice with a tolerance limit of 1 kg for weight and 1 cm for heights and circumferences. A third measurement was taken if the difference of the two measurements was greater than the tolerance limit. The average of the two closest measurements were used in the current analysis. BMI was calculated as the subject's weight in kilograms divided by the square of height in meters. WHR was calculated by dividing the subject's waist circumference in centimeters by hip circumference in centimeters. Study variables were grouped into quartiles based on distributions of the controls.

Odds ratios (OR) were used to measure the association of diabetes with BMI and WHR. Conditional logistic regression models were used to obtain maximum likelihood estimates of the odds ratios and their 95% confidence intervals (CI), after adjusting for potential confounders.[27] Tests for trend were performed by entering the categorical variables as continuous parameters in the models. Tests for interaction were performed by introducing a multiplicative interaction term into the logistic model. All analyses were performed using SAS 8.10 and all tests of statistical significance were based on two-sided probability.

Results

Demographics and suggested risk factors for diabetes are presented in Table 1. The average age was 56.4 y for cases and 55.9 y for controls. Compared to controls, cases tended to have less education and lower income, but higher caloric intake, BMI, WHR, and parity, and were more likely to have a history of hypertension. We found no significant differences between diabetes cases and women with glucosuria. All of these variables were adjusted for in the multiple regression analysis to control for potential confounding effects. There were no significant differences between cases and controls with regard to age, alcohol intake, smoking, regular exercise, oral contraceptive use, history of chronic pancreatitis, and age at diagnosis of hypertension.

Risk of diabetes increased significantly with all obesity measures, especially with measures of central obesity (Table 2). Compared to women weighing less than 54.0 kg, women weighing at least 65.5 kg had nearly twice the risk of diabetes (OR 1.79, 95% CI 1.25–2.59), after adjustment for nonanthropometric variables. Similarly, compared to women with a BMI of less than 22.06, women with a BMI of at least 26.57 had roughly 2.5 times the risk of diabetes (OR

Table 1 Comparison of cases and controls, by sample population, regarding demographics and selected diabetes risk factors[a]

	Diabetes cases (n = 345)	*Controls (n = 2760)*	P-*value*[b]	*Glucosuria cases (n = 566)*	*Comparison of diabetes and glucosuria cases,* P-*value*[b]
Age (y)	56.4	55.9		56.2	0.68
Education (%)					
None	21.5	17.3	<0.01	22.6	0.88
Elementary	20.6	14.4		19.3	
Middle/high school	51.0	56.2		52.1	
College and above	7.0	12.2		6.0	
Household income (Yuan) (%)					
<10,000	18.0	18.2	<0.01	20.9	0.73
10 000–19 999	46.7	38.0		44.5	
20 000–29 999	24.1	26.2		22.8	
≥30 000	11.3	17.6		11.8	
Exercise regularly during past 5 y (%)	38.0	42.1	0.13	37.1	0.79
Regular smoker (%)	4.1	3.1	0.35	5.5	0.34
Regular drinker (%)	1.5	2.5	0.22	1.8	0.71
Oral contraceptives (%)	25.2	24.1	0.65	24.4	0.78
Chronic pancreatitis (%)	0.3	1.0	0.24	0.2	0.72
Hypertension (%)	38.3	27.7	<0.01	37.1	0.73
Age at hypertension diagnosis (y)	44.1	46.3	0.23	44.6	0.69
Caloric intake (kcal/day)	1827	1693	<0.01	1815	0.69

[a]Values are mean (standard deviation) or percent of total reporting. [b]*P*-values for were derived from univariate conditional logistic regression analyses.

Table 2 Associations between anthropometric measurements and risk of diabetes. Shanghai Women's Health Study, 1997–2000[a]

		Cases/controls	OR	95% CI			*Cases/controls*	*OR*	*95% CI*
Weight (kg)					Waist circumference (cm)				
Q1	<54.0	48/673	1.0	Reference	Q1	<73.5	33/751	1.0	Reference
Q2	54.0–59.4	75/710	1.34	0.91–1.96	Q2	73.5–79.4	58/679	1.90	1.22–2.96
Q3	59.5–65.4	107/677	1.95	1.36–2.81	Q3	79.5–85.4	102/700	3.15	2.07–4.77
Q4	≥65.5	115/700	1.79	1.25–2.59	Q4	≥85.5	152/630	5.15	3.40–7.79
	Trend test			0.0004		Trend test			<0.0001
Height (cm)					Hip circumference (cm)				
Q1	<153.0	94/624	1.0	Reference	Q1	<92.0	55/659	1.0	Reference
Q2	153.0–156.9	106/739	0.92	0.67–1.25	Q2	92.0–96.4	70/725	1.09	0.75–1.58
Q3	157.0–160.0	79/745	0.68	0.49–0.94	Q3	96.5–101.9	103/661	1.68	1.17–2.40
Q4	≥160.1	66/652	0.63	0.44–0.91	Q4	≥102.0	117/715	1.67	1.17–2.39
	Trend test			0.003		Trend test			0.0006
Body mass index (kg/m^2)					Waist to hip ratio				
Q1	<22.06	40/681	1.0	Reference	Q1	<0.785	33/792	1.0	Reference
Q2	22.06–24.16	72/704	1.63	1.09–2.44	Q2	0.785–0.818	48/708	1.58	1.00–2.51
Q3	24.17–26.56	103/685	2.26	1.53–3.32	Q3	0.819–0.854	91/637	3.36	2.21–5.09
Q4	≥26.57	130/690	2.57	1.75–3.77	Q4	≥0.855	173/623	6.05	4.05–9.04
	Trend test			<0.0001		Trend test			<0.0001
Body mass index (kg/m^2)–WHO[b]									
Underweight	<18.5	1/77	0.16	0.02–1.19					
Normal weight	18.5–24.9	141/1573	1.00	Reference					
Overweight	25.0–29.9	161/941	1.71	1.33–2.19					
Obese	≥30.0	42/169	2.19	1.47–3.27					
	Trend test			<0.0001					

[a]Adjusted for education, income, caloric intake, and history of hypertension. [b]Cut-points defined by the World Health Organization (WHO).

2.57, 95% CI 1.75–3.77). An increased risk of diabetes was observed among overweight (OR 1.71, 95% CI 1.33–2.19) and obese (OR 2.19, 95% CI 1.47–3.27) women, as defined by standard World Health Organization (WHO) cut-points for BMI. Comparison of the highest quartile with the lowest quartile for waist circumference, hip circumference, and WHR yielded odds ratios of 5.15 (95% CI 3.40–7.79), 1.67 (95% CI 1.17–2.39), and 6.05 (95% CI 4.05–9.04), respectively. Although recent studies have implied that waist circumference alone can be an adequate predictor of central adiposity, WHR was used for further analysis in order to provide some adjustment for the frame size of Chinese women and to make our results comparable to earlier studies, which frequently used WHR as a measure of central adiposity.[28] Increasing height was inversely associated with risk of diabetes ($P = 0.003$). However, after additional adjustment for weight (data not shown), there was no association between height and diabetes ($P = 0.93$). All analyses were conducted among women with glucosuria ($n = 566$) and the subset of women tested at the designated study facilities ($n = 288$) with no significant differences in results (data not shown).

Further analyses were conducted to evaluate the joint and independent effects of BMI and WHR on the risk of diabetes (Table 3). WHR was positively associated with risk of diabetes at all levels of BMI. However, the positive relationship between BMI and the risk of diabetes weakened with increasing WHR. This pattern was observed using quartiles of BMI from our population as well as the standard WHO cut-points. After adjustment for BMI, risk of diabetes increased with increasing WHR regardless of BMI categorization (quartiles $P < 0.0001$, WHO $P < 0.0001$). However, following adjustment for WHR, BMI no longer predicted risk of diabetes (quartiles $P = 0.15$, WHO $P = 0.05$). Tests for multiplicative interaction between BMI and WHR were not statistically significant (quartiles $P = 0.09$, WHO $P = 0.05$). The analysis presented in Table 3 was also performed using the International Obesity Task Force's newly proposed BMI cut-point for adult Asians, with similar results (data not shown).[29]

Discussion

Our study, one of the largest population-based case–control studies of diabetes, indicated that central obesity, as measured by WHR, is an important predictor of diabetes risk among Chinese women. A clear dose–response relationship was observed between central obesity and risk of diabetes, particularly among nonobese and underweight women. Furthermore, we found that BMI conferred an increased risk of diabetes primarily among women with a relatively low WHR.

Our findings are consistent with those from previous epidemiological studies, including two earlier prospective studies of women in the US.[12,17] In the Nurses' Health Study, risk of type II diabetes was more strongly related to waist circumference than with BMI.[12] In the Iowa Women's Study, the dose–response relationship between risk of diabetes and WHR was much stronger than that with BMI.[17] Findings in support of waist measurements as an important indicator of risk for diabetes have also been reported in a number of prospective studies of men[11,13,14] These results may be explained, in part, by the fact that BMI does not accurately reflect percent of total body fat among individuals with significant visceral adiposity.[26] These cohorts, and individuals at risk for diabetes, are often older individuals. Consequently, age-related variation in lean body mass reduces the validity of BMI as a measure of adiposity.[26] In contrast, estimation of total fatness via abdominal circumference improves with age, implying that WHR may be a better predictor of risk of diabetes than BMI in aging populations.[26]

Analysis of the joint effects of BMI and WHR on risk of diabetes demonstrated the predictive strength of WHR across all levels of BMI. Although one would predict that individuals in the highest quartiles of both BMI and WHR should have a compounded risk of diabetes, the data suggest that there may be a limit to the risk conferred by increased adiposity. Persons with low overall adiposity increase their risk of diabetes most drastically by gaining fat centrally. Even persons considered obese can significantly increase their risk of diabetes by gaining fat in this region. However, increasing overall fat content conferred little, if any, additional risk among individuals in the higher quartiles of WHR. Biologically, these data may represent the fact the central and overall adiposity have both independent and common endocrine-based mechanisms of diabetes pathogenesis. Both contribute significantly to overall risk, yet central adiposity appears to have a more profound effect.

It is generally accepted that obesity, particularly central obesity, can have deleterious metabolic effects, thereby increasing the risk of developing various chronic diseases.[21] Expanded fat stores, a hallmark of obesity, results in increased lipolysis, causes a rise in circulating free fatty acids, and promotes peripheral and hepatic insulin resistance. In order to compensate for increased glucose production and insulin resistance, stimulation of insulin secretion occurs. While normal obese individuals can adjust to elevated plasma free fatty acids in such a manner, a subpopulation of obese individuals lack the ability to hypersecrete insulin.[30] Finally, recent data has suggested that progression to diabetes may also be associated with two hormones produced in adipocytes, leptin and resistin[31,32]

Central adiposity is believed to differ in physiology from fat stores elsewhere in the body. It was found that lipolysis occurs more frequently in visceral fat and is less sensitive to the antilipolytic effects of insulin than other fat stores.[33] In addition, it appears that the proximity of abdominal fat to the liver may deliver excess amounts of free fatty acids directly to the portal vein, thus increasing the hepatic burden of free fatty acids.[34] If true, it would follow that elevated levels of leptin and resistin may also be delivered into portal circulation in a similar fashion. These new biological links between obesity, glucose impairment, and diabetes further support the distribution and amount of fat content as risk factors for diabetes.

This study has several limitations. First, cases were identified from women who initially tested positive using nonfasting urine glucose tests. Although the specificity of such tests is near 100%, the sensitivity may range from 37–75%.[35] Therefore, it is possible that controls used in this

Table 3 Odds ratios and 95% confidence intervals for joint effects of WHR and BMI on the risk of diabetes. Shanghai Women's Health Study, 1997–2000[a]

Body mass index (kg/m²)	Waist to hip ratio								
	Case/control	WHR < 0.785	Case/control	WHR = 0.785–0.818	Case/control	WHR = 0.819–0.854	Case/control	WHR ≥ 0.855	OR adjusted for WHR
Quartiles									
<22.06	10/382	1.0 (Reference)	7/175	1.57 (0.58–4.21)	4/89	6.46 (2.75–15.22)	9/35	8.93 (3.35–23.77)	1.0 (reference)
22.06–24.16	8/222	1.34 (0.52–3.45)	14/204	2.50 (1.09–5.75)	19/159	4.80 (2.16–10.64)	31/119	9.50 (4.48–20.14)	1.17 (0.77–1.77)
24.17–26.56	8/113	2.73 (1.04–7.15)	13/186	2.58 (1.10–6.03)	33/180	6.43 (3.08–13.44)	49/206	8.50 (4.13–17.46)	1.30 (0.87–1.95)
≥26.57	7/75	3.12 (1.13–8.61)	14/143	3.50 (1.49–8.20)	25/209	4.17 (1.95–8.91)	84/263	10.52 (5.25–21.07)	1.34 (0.89–2.02)
OR adjusted for BMI		1.0 (reference)		1.51 (0.95–2.40)		3.10 (2.02–4.76)		5.47 (3.59–8.34)	
Test for multiplicative interaction				$P = 0.09$					
WHO classification[b]									
<25.0	21/651	1.0 (reference)	23/467	1.53 (0.83–2.81)	45/314	4.56 (2.65–7.84)	53/218	7.21 (4.21–12.36)	1.0 (reference)
25.0–29.9	9/127	2.13 (0.94–4.83)	23/215	3.13 (1.68–5.83)	39/272	4.14 (2.38–7.22)	90/327	7.92 (4.74–13.23)	1.24 (0.96–1.61)
≥30.0	3/14	5.71 (1.50–21.77)	2/26	2.04 (0.44–9.40)	7/51	4.21 (1.68–10.53)	30/78	9.48 (5.06–17.77)	1.39 (0.92–2.11)
OR adjusted for BMI		1.0 (reference)		1.52 (0.96–2.40)		3.10 (2.03–4.74)		5.40 (3.56–8.18)	
Test for multiplicative interaction				$P = 0.73$					

[a]Adjusted for education, income, caloric intake, and history of hypertension. [b]Cut-points defined by the World Health Organization (WHO).

study may actually have subclinical diabetes, thus biasing the risk estimate towards the null. Furthermore, there is the potential for selection bias since not all subjects with glucosuria were tested for diabetes. However, we found no differences between confirmed diabetes cases and all women with glucosuria regarding demographic and suggested risk factors for diabetes. Additionally, further analyses were conducted among all women with glucosuria, with no significant differences in results between them and confirmed diabetes cases. Second, because anthropometric measurements such as BMI and WHR are not single past exposures, but cumulative ones, the temporal sequence of body fat distribution and disease progression cannot be firmly established in this study. However, we excluded all subjects with a previous history of diabetes from this study, thus minimizing the potential effect of diabetes on the level of body fat and its distribution. Furthermore, since diabetes is a wasting disease, any potential bias resulting from prevalent diabetes would be conservative and tend to underestimate the risks. In addition, when analyses were performed using self-reported data for weight from age 50 y (7 y earlier than the mean age of diagnosis), the results were comparable to those reported in this paper (data not shown). As with any epidemiological investigation, unobserved confounders cannot be excluded and may skew our results.

Several strengths of this study should be noted as well. First, the population-based case–control design and high participation rate (92.7%) reduces potential selection biases. Second, subjects were interviewed before incidence cases of diabetes were diagnosed, thus eliminating the possibility of recall bias based on disease status. Third, the use of standardized measurements ensures that the anthropometric variables used in this study are comparable among study participants. Finally, our study population consists of a large number of subjects with normal and below average BMI, thus increasing the statistical power for studying the effect of central adiposity among nonobese subjects.

In summary, our study suggests that among Chinese women and aging populations, measures of central obesity are better predictors of risk of diabetes than measures of overall obesity. Importantly, this association holds true for nonobese and underweight women, as well. Our findings suggest that in a population with a low prevalence of obesity, WHR is an important and significant predictor of risk of diabetes.

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