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Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2013-003408
Article Type:	Research
Date Submitted by the Author:	24-Jun-2013
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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	Hypertension < CARDIOLOGY, General diabetes < DIABETES & ENDOCRINOLOGY, EPIDEMIOLOGY, PUBLIC HEALTH

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Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

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RUNNING HEADER: Obesity and prevalence of hypertension and T2DM in Chinese adults

Word Count:

Abstract: 249

Text: 2,533

Abstract:

Objective: To evaluate the changes in body mass index (BMI) and waist circumference (WC) and their associations with the prevalence of hypertension and type 2 diabetes (T2DM) in Chinese adults.

Design: Two consecutive population-based cross-sectional surveys.

Setting: A total of 12 districts and 7 counties in Shanghai, China.

Participants: 12,329 randomly selected participants of the survey in 2002-2003, and 7,423 randomly selected participants of the survey in 2009. All subjects were residents of Shanghai aged 35-74 years old.

Outcome measures: Measured BMI and WC. Previously-diagnosed and newly-identified hypertension and T2DM by measured blood pressure, fasting and post-load glucose.

Results: While the participants of the two surveys were comparable in BMI in each age group, the participants of the 2009 survey had significantly larger WC than those of the 2002-03 survey, with an annual percentage change (APC) being higher among subjects aged 45-49 years old in both men and women. The increase in prevalence of T2DM was observed in all age groups and also appeared more evident in subjects aged 45-49 years old. The prevalence of hypertension was observed to increase more rapidly in elderly men and middle-aged women. Obesity, both overt and central, was associated with the risk of the two diseases, but BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM.

Conclusion: The prevalence of central obesity and related chronic diseases has been increasing in Shanghai, China. Our findings provide useful information for the projection of a more rapidly growing burden of T2DM than hypertension in Chinese adults.

Keywords: type 2 diabetes; hypertension; prevalence; body mass index; waist circumference

Article summary

Article focus

- The shift in BMI and WC among Chinese adults over past one decade.
- The contribution of changes in overall and central obesity to the increasing burden of chronic disease in China.

Key messages

- The WC increased in Chinese adults over the decade spanning 2002-2009, while BMI did not change over the same period.
- BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM in Chinese adults.
- Our findings provide useful information for the projection of a more rapidly growing burden of T2DM than hypertension in Chinese adults.

Strengths and limitations of this study

- The strengths of this study include the strict process of multistage sampling in adult population of Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.
- The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM.
- The differences in several demographic characteristics between the participants of the two surveys indicate the possibility of selection bias.

Introduction

A rising worldwide prevalence of chronic disease, manifested primarily as hypertension and type 2 diabetes (T2DM), has been well documented [1-4]. In Chinese aged 15-74 years old, the prevalence of hypertension increased from 5.11% in 1959, 7.73% in 1979 [5] and 13.58% in 1991[6] to 17.65% in 2002 **[7]**. The prevalence of T2DM tripled between 1980 (about 1.0%) and 1996 (3.2%) [8 9], and reached 9.7% in 2008 among adults at 20 years old or above [10]. It is estimated that over 92 million people in China have T2DM. This represents approximately half of the world's diabetic population, and places China at the "global epicenter of the diabetes epidemic" [4].

Both hypertension and T2DM are associated with obesity [11 12]. Obesity is often measured by body mass index (BMI). Across the entire range of BMI, the risk of hypertension and T2DM increases, making a higher BMI a strong predictor of both hypertension and T2DM [4 12-14]. However, a significant proportion of Asian adults diagnosed with T2DM are with the normal BMI, ie.18.5-25.0 kg/m^2 [15 16]. BMI is a general indicator of overt obesity, but does not give information about the distribution of obesity. Central obesity, often assessed via waist circumference (WC), is also strongly correlated with T2DM in both European and Asian adults [11 17]. While changes in BMI have been well documented in China over past several decades [2 18], changes in WC, and thus central obesity, are not well described.

In this study, we took advantage of the data from population based cross-sectional surveys conducted in Shanghai in 2002-03 and in 2009. We used the data from the two surveys to evaluate correlations between shifts in BMI and WC with the prevalence of hypertension and T2DM in Chinese adults. Our results may help to better understand the contribution of overall obesity and central obesity in the increasing burden of chronic disease in China.

Materials and Methods

Study Participants

A representative sample of the general population was randomly selected through a multistage sampling process in the 2002-03 survey. Firstly, 4 districts and 2 counties were randomly selected

from a total of 12 districts and 7 counties in Shanghai, China. And then, 1-2 sub-districts or towns were randomly selected from each selected district or county. Next, 1-2 communities or villages, usually 1,000-2,000 residents for each, were randomly selected from each selected sub-district or town. Finally, eligible subjects (permanent residents of Shanghai, 15-74 years old and having been in the city for at least 5 years) were randomly selected from the selected communities and villages and were invited for participation. Pregnant women, individuals with type I diabetes, and physically or mentally disabled persons were excluded from the participation. During the period of May 2002-October 2003, a total of 17,526 eligible subjects were recruited, and 14,401 (82.17%) participated the survey.

The 2009 survey used the similar sampling method except that only 7 communities and villages were randomly selected in the third stage of sampling. The inclusion and exclusion criteria of the 2009 survey were also similar to those for the 2002-03 survey, except that only those at the age of 35-74 years old were eligible for the 2009 survey. Among 7,627 eligible adults contacted during the period of May-July 2009, 7,414 (97.21%) were interviewed and donated blood samples.

To make the two surveys comparable, we excluded 1,071 subjects younger than 35 years from the 2002-03 survey. After further excluding subjects with missing information, the final analysis included 5,050 men and 7,279 women in the 2002-03 survey and 3,461 men and 3,962 women in the 2009 survey. The Institutional Review Board at Shanghai Municipal Center of Disease Control and Prevention approved the study. Informed consent was obtained from each participant before data collection.

Data Collection

A similar survey approach was followed by the two investigations. In both surveys, information on demographic and socioeconomic factors, diagnosis of diabetes, tobacco and alcohol use, physical activity and family history of diabetes was collected by trained interviewers with a structured questionnaire at community clinics located in the residential areas of the participants.

At the interview, each participant's blood pressure, body weight, standing height, and waist

circumference (WC) were measured by trained staff. Blood pressure was measured on the right arm in the sitting position using standard mercury sphygmomanometer after at least 5 minutes of rest. The first and fifth Korotkoff sounds were recorded. Body weight and height were recorded while the subject was in light clothing and without shoes. Body weight was measured with electronic scales to the nearest 0.1 kg. Body height was measured to the nearest 0.1 cm by using a stadiometer. WC, recorded to the nearest 0.1 cm, was taken with a cloth tape and was measured on bare skin at the midline between the lower border of the ribs and the iliac crest in the horizontal plane after a normal expiration. Two measurements were taken and the mean of the replicates was used in the following analyses. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2) using the direct measurements.

Laboratory Measurements

After at least 10 hours of overnight fasting, 1-1.5 ml venous blood specimen was collected in a vacuum tube containing sodium fluoride. All participants with no history of diabetes and having a fasting plasma glucose level of < 7.0 mmol per liter (mmol/l) were then asked to have an oral glucose-tolerance test (OGTT). Blood samples were drawn at 0 and 120 minutes after a standard 75 gram glucose load. Plasma glucose was measured with Glucose oxidase-peroxidase (GOD-PAP) method.

Diagnosis of T2DM and Hypertension

Previously diagnosed T2DM and hypertension was identified by a positive response from the participant to the question of "Have you ever diagnosed with T2DM/hypertension by a doctor?" and confirmed by medical records in which prescriptions of anti-hypertensive or hypoglycemic medications were presented. The consistent rate was 100%. For those who had a negative response, the T2DM was diagnosed with measured glucose level by using the 1999 World Health Organization diagnostic criteria [Department of Noncommunicable Disease Surveillance. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1. Diagnosis and classification of diabetes mellitus. Geneva: World Health

Organization, 1999. (Accessed July 5, 2010, at http://www.staff.ncl.ac.uk/philip.home/who_dmg.pdf.)] and hypertension referred to the subjects with measured systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg and confirmed by clinical visits. Total T2DM and hypertension included both previously diagnosed and newly-diagnosed patients. 42.7% (1,110 of 2,598) diabetic patients and 10.3% (694 of 6,735) hypertensive patients were newly-diagnosed in the two surveys.

Statistical Analysis

SAS software 9.2 was used for all the statistical analyses. Characteristics of the subgroups were described using summary statistics (median, 25th and 75th percentile, frequencies, and percentages) separately for men and women. The differences between two surveys were compared using χ^2 test (category variables) and Wilcoxon tests (continuous variables). The annual percentage changes (APC) in prevalence between two surveys were calculated as (prevalence in 2009 – prevalence in 2002-03) / number of years using logarithms for each age group. Percentile curves were constructed for BMI and WC values in the two surveys by gender using the LMS (lambda, mu, sigma) method. Restricted cubic splines (RCS) were used to model a potential curvilinear relationship of BMI and WC with hypertension and diabetes using the 5th, 25th, 75th and 95th percentiles as fixed knots and the 50th percentile as the reference. Polynomial logistic regression were used to estimate the odds ratios (OR) and 95% confidence intervals (95% CI) of BMI and WC with T2DM and hypertension. Meta-analysis was applied to obtain the combined ORs and 95% CI considering the potential heterogeneity of the populations in the two surveys. The residual method was used to derive the independent effect of BMI and WC with each other in the models. *P* value less than 0.05 was considered as a test of significance based on two sides.

Results

The male participants in two surveys were similar in age, resident site and cigarette smoking while the females were comparable in cigarette smoking ($P > 0.05$) (Table 1). Compared to the subjects in 2002-03 survey, the participants of 2009 survey, both men and women, had lower level

of education, higher level of income per capita, more prior history of T2DM, higher frequency of alcohol drinking and lower frequency of leisure time activity, and were more likely to have a family history of diabetes.

Figure 1 shows the shapes of the BMI and WC distribution curves among men and women changed over the period of the two surveys. After adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, and family history of T2DM, the curves of BMI were almost overlapped in both men and women. However, the WC curves for men and women were shifted to the right between 2002-03 and 2009, with the mean WC increasing from 83.6 to 85.3 cm for men and from 78.4 to 80.6 cm for women.

As presented in table 2, the prevalence of obesity, both overall and central, increased with increasing age groups. While the prevalence of overall obesity (BMI $\geq$ 28 kg/m^2) did not changed between two surveys (all P values > 0.05), the prevalence of central obesity were significantly higher in 2009 survey in each age group (all P values < 0.001). A more pronounced increase in prevalence of central obesity and T2DM was observed among subjects aged 45-49 years old in both men and women; whereas the change in prevalence of hypertension between two surveys appeared more evident in older men and younger women over the period. Using the World Health Organization (WHO) criteria for obesity did not change the results substantially (data not shown in the tables).

BMI and WC were highly correlated with each other, with a correlation coefficient of 0.77 (P < 0.0001) among men and 0.78 (P < 0.0001) among women after adjusting for age. Therefore, the residual method was used to test the potential respective non-linear relationships of BMI and WC with the risk of T2DM and hypertension (Figure 2). The dose-response analysis likewise showed a statistically significant increased risk of T2DM at high level of WC and a significant elevated risk of hypertension at high level of BMI in both men and women after adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, family history of T2DM and phase of surveys, with P values for non-linear relationship tests < 0.05. No significant relationship was

observed between BMI and T2DM in men and between WC and hypertension in women.

As shown in table 3, in both sexes, BMI adjusted for WC (residuals) appeared more strongly associated with hypertension while WC adjusted for BMI (residuals) was more evidently related with T2DM. Comparing with the lowest quartile of BMI residuals, the risk of hypertension increased 85% (95%CI: 1.59-2.15) in men and 1.23-fold (95%CI: 1.94-2.57) in women, whereas the risk of T2DM did not increase significantly in both sexes. On the other hand, the ORs of the highest versus the lowest quartile WC residuals for T2DM were 1.75 (95%CI: 1.33-2.30) in men and 2.37 (95%CI: 1.78-3.15) in women, higher than the OR of 1.57 (95%CI: 1.35-1.82) in men and 1.13 (95%CI: 0.98-1.30) in women for hypertension.

We further evaluated the potential joint effect of BMI and WC on T2DM and hypertension (table 4). The participants were classified into normal weight (BMI 18.5-23.9 kg/m^2), overweight (24.0-27.9 kg/m^2), or obese (≥ 28 kg/m^2) based on data from Chinese adults, and were defined as with normal or increased WC using sex-specific cut-offs (85 cm in men and 80 cm in women) [19]. The risk of T2DM and hypertension increased across groups defined by BMI and WC, with the highest risk observed among men with the lowest BMI but a higher WC, and among those with the highest BMI and a higher WC for hypertension. However, no significant interaction was observed between BMI and WC (all *P* values for interaction tests > 0.05).

Discussion

In this representative sample of the adult population in Shanghai, the largest city in China, we observed an increased prevalence of central obesity, hypertension and T2DM over the decade spanning 2002-2009. In contrast, BMI did not change over the same period. Our results present a snapshot of overt versus central obesity in the Chinese population and suggest that the epidemic of central obesity in this population, which has been more closely associated with the prevalence of T2DM, may lead to a more rapidly growing burden of T2DM in China.

Chinese adults have lower rates of overweight and obesity than their Western counterparts using the WHO criteria (BMI ≥ 25 kg/m^2 for overweight and BMI ≥ 30 kg/m^2 for obesity) [15 16].

Nevertheless, increasing trends of BMI in Chinese adults have been well documented [18 20]. In two national nutritional surveys undertaken in 1982 and 1992 in China, the prevalence of overweight/obesity (BMI $\geq$ 25 kg/m^2) in subjects 20-70 years of age was 10% and 15%, respectively. Between 1992 and 2002, the combined prevalence of overweight and obesity increased from 14.6 to 21.8% [21]. Interestingly, the increase in BMI among Chinese adults has slowed down during past decades [2]. In this study, we did not observe an increase in BMI and prevalence of obesity defined by the Chinese obesity standards or by WHO criteria (data not shown). Instead, we observed a significant increase in WC, a measure of central obesity between surveys. Our observation of increased WC in Chinese adults, without a concomitant increase in BMI, represents an increasing burden of central obesity in this population. The increase in central obesity indicates an upward trend in body fat percentages in the population who have been previously observed with higher body fat percentages compared to other ethnic people with the same BMI [22 23].

Both epidemic of overall and central obesity parallel a continuously increasing prevalence of hypertension and T2DM in China [21]. Several studies indicate that overall obesity (BMI) is more strongly associated with hypertension, while central obesity (WC) is more strongly associated with T2DM [17 24-26]. The rationale for these associations is based on the notion that central obesity reflects specific accumulation of visceral adipose tissue. Excess visceral adipose tissue is metabolically unfavorable due to productions of free fatty acids and inflammatory mediators. Overall obesity, on the other hand, represents a greater overall physiologic strain and effects vascular and cardiac parameters more significantly. In this study, we observed a significant increase in prevalence of T2DM regardless of gender or age groups, which was more pronounced than the change in the prevalence of hypertension during the period of 2002-03 and 2009. We also observed a closer association of central obesity with the prevalence of T2DM than with the prevalence of hypertension. These results support the notion that central obesity in particular is a stronger risk factor for T2DM than for hypertension in Chinese adults. Due to the cross-sectional design, however, our study was unable to make a causal inference.

The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM. The differences in several demographic characteristics between the participants of the two surveys indicate the possibility of selection bias. However, there are several strengths, including the strict process of multistage sampling in adult population in Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.

Conclusions

In summary, this study describes the potential association of central obesity with an upward trend of T2DM, implicating a more rapidly growing burden of T2DM than hypertension in Chinese adults. The findings in Shanghai, the largest city and one of the most economically developed areas in China, provide useful information for the projection of future trends in the whole country.

Acknowledgements

We thank Dr. Xiao-ou Shu and Dr. Hui Cai of Vanderbilt University for their contributions in study design and data analysis. The authors thank the study participants of the two cross-sectional surveys and the healthcare workers in each community involved.

Footnotes

Contributors YR and MM contributed to data collection, data analysis and draft of the paper. YR, YYL, QDY, and LS contributed to data collection and quality control. LJM contributed to revision of the paper. HZ contributed to data clean and analysis. RL and WHX contributed to study design, statistical analysis and revision of the paper. All authors contributed to the interpretation of data and revision of the manuscript. All authors approved the final version.

Funding This study was supported by the Key Program of Shanghai Municipal Committee of Science and Technology (04 DZ19502), the Shanghai Medical Development Program (01ZD001) and the Shanghai Municipal Health Bureau (GWDTR201204). W. H. Xu was supported by a training grant from the Fogarty International Center (D43 TW008313 to X. O. Shu). The funders had no role in study design, data collection or analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest: None declared.

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Figure 1. Shift in BMI and WC over the period of the two population-based surveys

Figure 2. Non-linear dose-response relationship of BMI and WC with hypertension and T2DM among participants of the two population-based surveys

362 Table 1. Characteristics of participants in two population-based surveys in Shanghai, China

Characteristics	1st survey		2nd survey		*P-value between surveys* [a]	
	Men (N=5,050)	Women (N=7,279)	Men (N=3,461)	Women (N=3,962)	*In men*	*In women*
Age (yrs., mean ± SD)	54.8 ± 10.8	53.1 ± 10.3	54.7 ± 9.5	54.7 ± 9.1	0.55	<0.0001
Resident site (%)						
Urban	71.1	63.0	72.4	72.0		
Rural	29.0	37.0	27.7	28.0	*0.19*	*<0.0001*
Education (%)						
No formal education	4.1	18.4	3.2	9.5		
Primary school	18.2	23.0	14.7	17.7		
Middle school	35.3	31.1	45.7	45.2		
High school	27.6	22.6	27.6	23.8		
Colleague or above	14.8	4.9	8.8	3.9	*0.0025*	*<0.0001*
Per capita income (yuan/mo.) (%)						
<1000	37.0	45.5	4.9	4.0		
1000-2999	38.3	38.4	41.8	46.7		
3000-5000	22.5	17.9	33.2	33.3		
>5000	2.2	1.3	20.0	16.0	*<0.0001*	*<0.0001*
Family history of type 2diabetes	12.3	13.1	16.4	19.0	*<0.0001*	*<0.0001*
Prevalence of type 2diabetes (%)	13.6	10.3	17.4	14.1	*<0.0001*	*<0.0001*
Prevalence of hypertension (%)	34.8	28.3	41.8	37.1	*<0.0001*	*<0.0001*
Cigarette smoking (%)	61.4	1.7	62.6	1.8	*0.22*	*0.93*
Alcohol drinking (%)	40.4	2.4	54.0	5.0	*<0.0001*	*<0.0001*
Leisure-time activity (%)	13.3	13.1	10.8	9.0	*0.0009*	*<0.0001*

363 [a] *P* for Wilcoxon tests or chi-square tests

Table 2. Prevalence of obesity, hypertension and type 2 diabetes in participants of the two population-based surveys by age groups in Shanghai, China

	No. of subjects		Overall Obesity		*APC*	Central obesity		*APC*	Hypertension		*APC*	Type 2 diabetes		*APC*
	1st survey	2nd survey	1st survey	2nd survey	*(%)*	1st survey	2nd survey	*(%)*	1st survey	2nd survey	*(%)*	1st survey	2nd survey	*(%)*
Men														
Overall	5050	3461	11.7	11.9	*0.21*	46.3	53.8	*2.35*	34.8	41.8	*2.87*	13.6	17.4	*3.78*
Age-groups														
35-	414	230	10.5	9.1	*-2.11*	41.8	45.2	*1.22*	15.2	11.7	*-3.92*	4.6	5.7	*3.25*
40-	574	302	10.0	8.3	*-2.83*	41.8	47.00	*1.85*	22.5	21.9	*-0.43*	7.8	7.6	*-0.44*
45-	837	445	12.6	12.6	*-0.04*	44.0	53.7	*3.12*	25.3	31.0	*3.16*	7.8	13.7	*9.13*
50-	833	739	12.2	10.8	*-1.76*	44.1	53.8	*3.12*	33.1	40.3	*3.07*	12.7	18.3	*5.72*
55-	628	669	10.4	13.2	*3.78*	47.3	54.6	*2.25*	35.4	45.6	*3.99*	15.0	17.9	*2.82*
60-	507	513	10.5	15.4	*6.18*	48.7	56.1	*2.19*	44.6	51.7	*2.29*	15.6	20.1	*3.98*
65-	674	313	12.6	11.8	*-0.99*	51.4	61.0	*2.67*	49.4	59.4	*2.88*	20.8	26.2	*3.64*
70-	583	250	13.8	9.6	*-5.40*	51.1	54.0	*0.85*	50.9	65.2	*3.87*	24.2	25.6	*0.88*
Women														
Overall	7279	3962	13.8	13.8	*0.02*	41.7	54.2	*4.10*	28.3	37.1	*4.28*	10.3	14.1	*4.84*
Age-groups														
35-	615	251	7.5	7.2	*-0.65*	22.6	26.3	*2.35*	6.8	10.8	*7.24*	3.3	4.0	*3.17*
40-	1000	287	9.4	11.2	*2.66*	27.6	38.0	*5.05*	11.7	15.7	*4.61*	4.1	5.9	*5.81*
45-	1491	563	11.0	9.8	*-1.82*	32.3	42.6	*4.38*	19.3	23.5	*3.03*	5.8	8.7	*6.32*
50-	1309	866	15.1	14.1	*-1.00*	43.9	54.0	*3.24*	28.7	31.0	*1.16*	8.3	9.4	*1.94*
55-	838	818	15.7	13.6	*-2.17*	47.5	60.6	*3.83*	33.9	39.7	*2.48*	8.8	15.3	*8.80*
60-	610	585	19.2	18.1	*-0.87*	53.5	63.1	*2.58*	40.5	52.8	*4.17*	16.7	19.2	*2.11*
65-	799	327	18.0	18.4	*0.28*	59.0	66.1	*1.76*	48.4	59.3	*3.17*	23.7	27.8	*2.54*
70-	617	265	18.2	16.6	*-1.36*	60.2	68.7	*2.05*	51.4	64.5	*3.57*	21.4	27.2	*3.75*
All subjects														
Overall	12329	7423	13.0	12.9	*-0.05*	43.6	54.0	*3.35*	31.0	39.3	*3.75*	11.7	15.6	*4.53*
Age-groups [a]														
35-	1029	481	8.7	8.0	*-1.04*	30.3	33.9	*2.39*	10.2	11.2	*1.49*	3.8	4.7	*3.63*
40-	1574	589	9.6	10.1	*0.11*	32.7	41.3	*4.14*	15.6	17.9	*2.92*	5.5	6.5	*3.41*
45-	2328	1008	11.6	10.8	*-0.77*	36.5	46.6	*4.16*	21.5	26.2	*3.46*	6.5	10.5	*8.22*
50-	2142	1605	13.9	12.8	*-1.53*	44.0	53.9	*3.19*	30.4	34.6	*0.90*	10.0	12.8	*4.69*
55-	1466	1487	13.4	13.4	*0.01*	47.4	58.1	*3.13*	34.5	42.2	*3.20*	11.5	16.4	*5.75*
60-	1117	1098	15.2	16.9	*1.59*	51.3	59.9	*2.39*	42.4	52.3	*3.29*	16.2	19.6	*2.96*
65-	1473	640	15.6	15.4	*-0.39*	55.5	63.8	*2.11*	48.9	59.4	*3.04*	22.3	27.1	*2.98*
70-	1200	515	16.0	13.2	*-2.94*	55.8	61.5	*1.52*	51.2	64.9	*3.71*	22.8	26.4	*2.32*

[a] adjusted for sex according to the distribution in the first survey.

Table 3. Association of body size with hypertension and type 2 diabetes in two population-based surveys in Shanghai, China

	No. of subjects with neither diseases	Type 2 diabetes only		Hypertension only		Both	
		N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
BMI residuals							
Men							
Q1	1260	156	1.00	529	1.00	175	1.00
Q2	1224	142	0.99 (0.77, 1.27)	583	1.16 (1.00, 1.34)	172	1.11(0.87, 1.41)
Q3	1164	132	1.09 (0.84, 1.41)	651	1.50 (1.29, 1.74)	171	1.36(1.07, 1.73)
Q4	1079	123	1.16 (0.88, 1.51)	709	1.85 (1.59, 2.15)	207	1.95(1.54, 2.47)
	P for trend		*0.2472*		*<0.0001*		*<0.0001*
Women							
Q1	1816	166	1.00	600	1.00	223	1.00
Q2	1866	148	1.02 (0.80, 1.29)	629	1.29 (1.12, 1.48)	162	0.96(0.77, 1.21)
Q3	1835	125	0.89 (0.69, 1.15)	687	1.51 (1.31, 1.73)	158	1.03(0.82, 1.31)
Q4	1634	109	0.94 (0.73, 1.23)	847	2.23 (1.94, 2.57)	215	1.85(1.15, 2.98)
	P for trend		*0.4864*		*<0.0001*		*0.0067*
All subjects							
Q1	3048	330	1.00	1162	1.00	385	1.00
Q2	3079	282	1.00 (0.84, 1.19)	1200	1.22 (1.11, 1.35)	363	1.03(0.87, 1.22)
Q3	2998	278	0.98 (0.82, 1.18)	1346	1.50 (1.36, 1.67)	302	1.18(1.00, 1.40)
Q4	2753	211	1.04 (0.86, 1.26)	1527	2.05 (1.85, 2.27)	433	1.88(1.60, 2.21)
	P for trend		0.2280		*<0.0001*		*<0.0001*
WC residuals							
Men							
Q1	1376	102	1.00	531	1.00	111	1.00
Q2	1232	131	1.34 (1.02, 1.78)	601	1.23 (1.06, 1.42)	155	1.41(1.07, 1.84)
Q3	1130	148	1.39 (0.70, 2.77)	644	1.39 (1.20, 1.62)	197	1.73(1.33, 2.25)
Q4	989	172	1.75 (1.33, 2.30)	696	1.57 (1.35, 1.82)	262	2.25(1.74, 2.90)
	P for trend		*<0.0001*		*<0.0001*		*<0.0001*
Women							
Q1	2019	80	1.00	598	1.00	108	1.00
Q2	1935	102	1.17 (0.86, 1.59)	651	1.04 (0.91, 1.18)	117	0.94(0.71, 1.25)
Q3	1708	172	2.04 (1.54, 2.70)	732	1.14 (0.99, 1.30)	194	1.40(1.08,1.82)
Q4	1489	194	2.37 (1.78, 3.15)	782	1.13 (0.98, 1.30)	339	2.06(1.26, 3.38)
	P for trend		*<0.0001*		*0.0216*		*<0.0001*
All subjects							
Q1	3453	161	1.00	1109	1.00	203	1.00
Q2	3192	260	1.26 (0.99, 1.60)	1211	1.12 (1.01, 1.23)	260	1.16(0.82, 1.62)
Q3	2838	301	1.66 (1.16, 2.36)	1373	1.25 (1.13, 1.38)	412	1.55(1.29, 1.87)
Q4	2395	379	2.03 (1.66, 2.47)	1542	1.34 (1.09, 1.64)	608	2.18(1.83, 2.61)
	P for trend		*0.0001*		*0.0021*		*<0.0001*

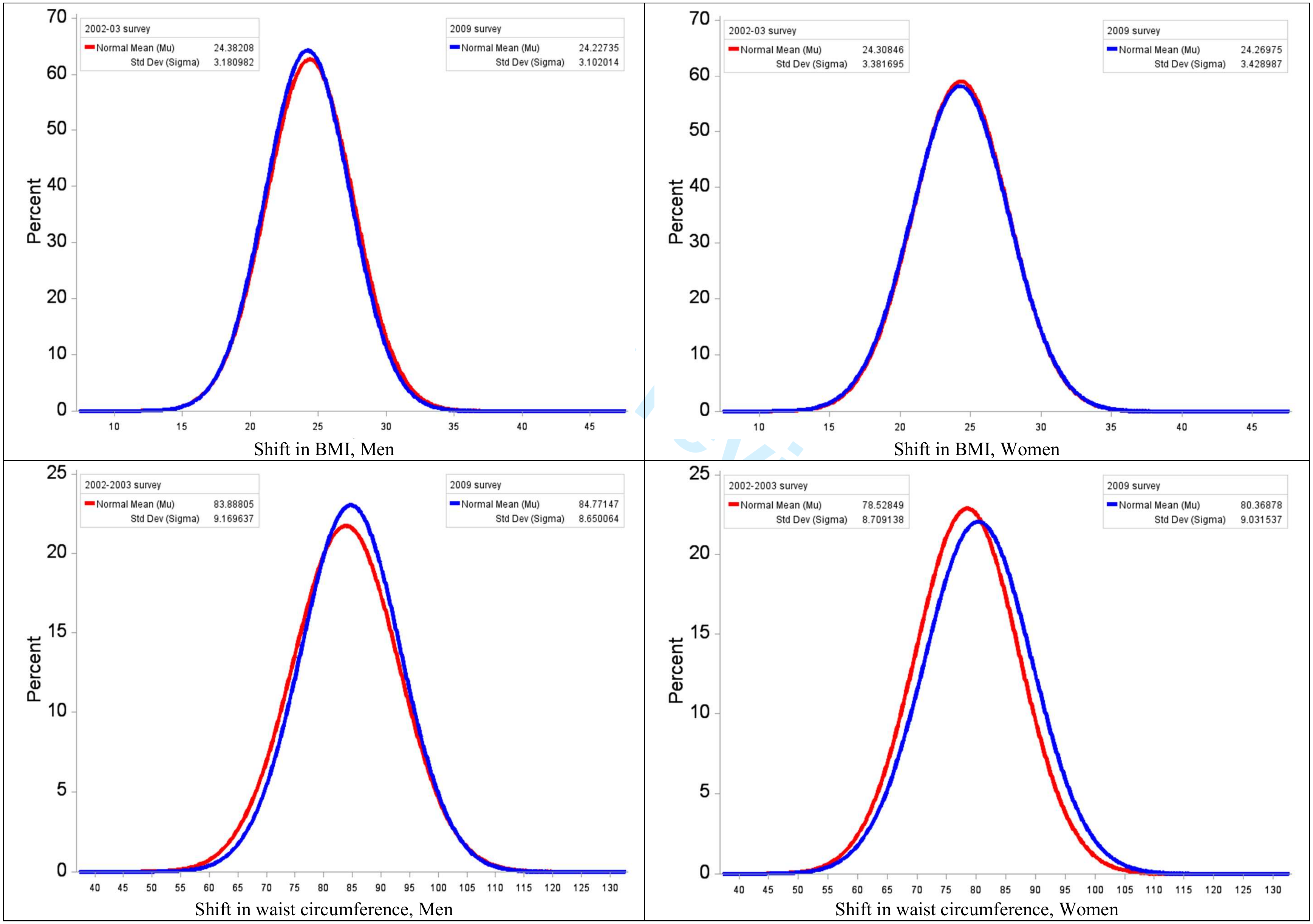
Missing value excluded from the analysis.
OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), phase of study (first /second survey); Additionally adjusted for sex (male/female) for all subjects.

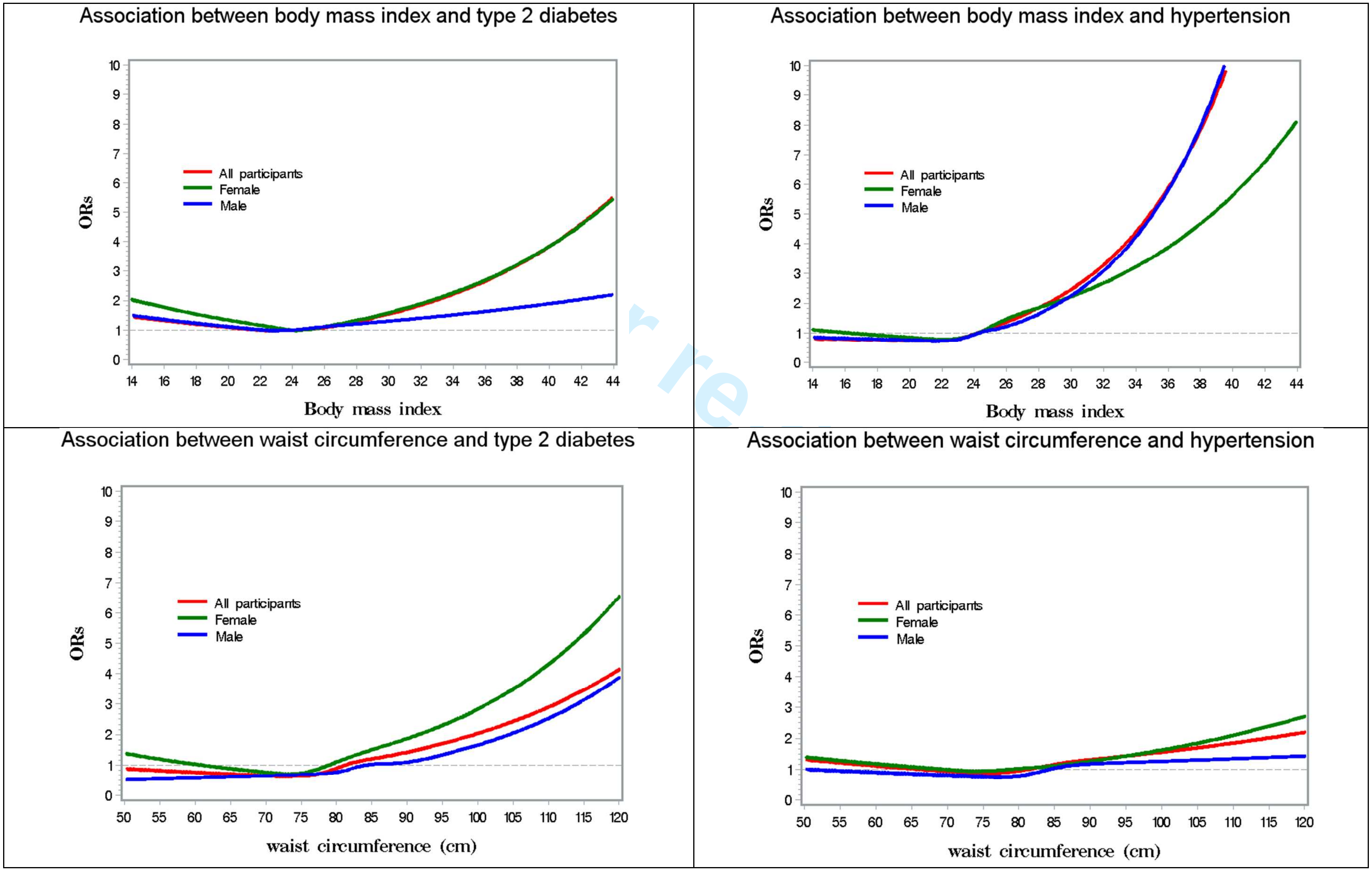
Table 4. Joint effect of general obesity and central obesity on type 2 diabetes among Chinese adults

BMI	WC：Lower			WC: Higher			OR (95%CI) for hypertension		OR (95%CI) for type 2 diabetes	
	No. of subjects	Hypertension N (%)	Diabetes N (%)	No. of subjects	Hypertension N (%)	Diabetes N (%)	WC: Lower	WC: Higher	WC: Lower	WC: Higher
Men										
<18.5	212	36	20	16	10	6	0.61(0.42, 0.89)	3.68(1.28, 10.59)	1.02(0.62, 1.67)	3.77(1.13, 12.56)
18.5-23.9	3034	767	296	679	249	111	1.00	1.56(0.94, 2.57)	1.00	1.48(1.15, 1.90)
24.0-27.9	1010	356	134	2530	1179	483	1.61(1.13, 2.32)	2.38(1.78, 3.17)	1.46(1.16, 1.83)	1.85(1.16, 2.96)
⩾28.0	36	20	4	960	580	224	3.91(1.95, 7.82)	4.67(3.97, 5.49)	1.71(0.55, 5.37)	2.60(2.12, 3.18)
						P for interaction	*0.0711*		*0.0933*	
Women										
<18.5	313	51	19	8	2	1	0.68(0.49, 0.94)	0.85(0.16, 4.51)	0.93(0.56, 1.54)	2.45(0.22, 26.72)
18.5-23.9	4323	821	265	974	314	165	1.00	1.48(1.26, 1.75)	1.00	2.36(1.89, 2.94)
24.0-27.9	1330	384	93	2724	1102	437	1.84(1.59, 2.14)	2.21(1.97, 2.49)	1.19(0.92, 1.53)	2.14(1.81, 2.54)
≥28.0	81	32	9	1467	815	317	3.10(1.93, 5.00)	4.33(3.77, 4.96)	2.14(1.01, 4.52)	3.08(2.56, 3.71)
						P for interaction	*0.3524*		*0.4011*	
Total										
<18.5	525	87	39	24	12	7	0.65(0.51, 0.83)	2.25(0.85, 5.93)	0.97(0.68, 1.39)	3.45(1.18, 10.12)
18.5-23.9	7357	1588	561	1653	563	276	1.00	1.52(1.25, 1.85)	1.00	1.88(1.42, 2.49)
24.0-27.9	2340	740	227	5254	2281	920	1.74(1.50, 2.03)	2.31(2.03, 2.62)	1.33(1.12, 1.58)	1.99(1.62, 2.45)
⩾28.0	117	5	13	2427	1395	541	3.34(2.26, 4.94)	4.46(4.02, 4.96)	2.00(1.07, 3.74)	2.85(2.49, 3.27)
						P for interaction	*0.0562*		*0.0798*	

Higher WC defined as ≥ 85 cm for men and ≥ 80 cm for women

OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), and phase of study (first /second survey).


2002-03 survey
Normal Mean (Mu) 24.38208
Std Dev (Sigma) 3.180982
2009 survey
Normal Mean (Mu) 24.22735
Std Dev (Sigma) 3.102014
Percent
Shift in BMI, Men
2002-03 survey
Normal Mean (Mu) 24.30846
Std Dev (Sigma) 3.381695
2009 survey
Normal Mean (Mu) 24.26975
Std Dev (Sigma) 3.428987
Percent
Shift in BMI, Women
2002-2003 survey
Normal Mean (Mu) 83.88805
Std Dev (Sigma) 9.169637
2009 survey
Normal Mean (Mu) 84.77147
Std Dev (Sigma) 8.650064
Percent
Shift in waist circumference, Men
2002-2003 survey
Normal Mean (Mu) 78.52849
Std Dev (Sigma) 8.709138
2009 survey
Normal Mean (Mu) 80.36878
Std Dev (Sigma) 9.031537
Percent
Shift in waist circumference, Women


Association between body mass index and type 2 diabetes
ORs
All participants
Female
Male
Body mass index
Association between body mass index and hypertension
ORs
All participants
Female
Male
Body mass index
Association between waist circumference and type 2 diabetes
ORs
All participants
Female
Male
waist circumference (cm)
Association between waist circumference and hypertension
ORs
All participants
Female
Male
waist circumference (cm)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Results of check
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	We have indicated that the study was based on two population-based cross-sectional surveys in the title and the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Line 53-62
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Line 72-87
Objectives	3	State specific objectives, including any prespecified hypotheses	Line 89-92
Methods			
Study design	4	Present key elements of study design early in the paper	Line 95-104
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Line 95-104
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Line 95-104
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Line 117-153
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Line 117-153
Bias	9	Describe any efforts to address potential sources of bias	Line 117-153
Study size	10	Explain how the study size was arrived at	NA
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Line 155-169
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Line 155-169
		(*b*) Describe any methods used to	Line 166-167

		examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	There were very few missing data in this study. Please see footnote of the Table 3
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	No
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Line 95-105
		(b) Give reasons for non-participation at each stage	No information
		(c) Consider use of a flow diagram	No
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Line 172-177, and Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Yes, we provide number of subjects for each variable of interest (Please see tables)
Outcome data	15*	Report numbers of outcome events or summary measures	Yes (Please see tables)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	No. Due to the large table, we present only adjusted ORs
		(*b*) Report category boundaries when continuous variables were categorized	Yes (Please see table 4)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Line 210-217
Discussion			
Key results	18	Summarise key results with reference to study objectives	Line 219-224
Limitations	19	Discuss limitations of the study, taking into account sources of	Line 253-259

		potential bias or imprecision. Discuss both direction and magnitude of any potential bias	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Line 251-252
Generalisability	21	Discuss the generalisability (external validity) of the study results	Line 263-264
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Line 275-280

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2013-003408.R1
Article Type:	Research
Date Submitted by the Author:	26-Aug-2013
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Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Epidemiology, Public health
Keywords:	Hypertension < CARDIOLOGY, General diabetes < DIABETES & ENDOCRINOLOGY, EPIDEMIOLOGY, PUBLIC HEALTH

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Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

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RUNNING HEADER: Obesity and prevalence of hypertension and T2DM in Chinese adults

Word Count:

Abstract: 249

Text: 2,658

Abstract:

Objective: To evaluate the changes in body mass index (BMI) and waist circumference (WC) and their associations with the prevalence of hypertension and type 2 diabetes (T2DM) in Chinese adults.

Design: Two consecutive population-based cross-sectional surveys.

Setting: A total of 12 districts and 7 counties in Shanghai, China.

Participants: 12,329 randomly selected participants of the survey in 2002-2003, and 7,423 randomly selected participants of the survey in 2009. All subjects were residents of Shanghai aged 35-74 years old.

Outcome measures: Measured BMI and WC. Previously-diagnosed and newly-identified hypertension and T2DM by measured blood pressure, fasting and post-load glucose.

Results: While the participants of the two surveys were comparable in BMI in each age group, the participants of the 2009 survey had significantly larger WC than those of the 2002-03 survey, with an annual percentage change (APC) being higher among subjects aged 45-49 years old in both men and women. The increase in prevalence of T2DM was observed in all age groups and also appeared more evident in subjects aged 45-49 years old. The prevalence of hypertension was observed to increase more rapidly in elderly men and middle-aged women. Obesity, both overt and central, was associated with the risk of the two diseases, but BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM.

Conclusion: The prevalence of central obesity and related chronic diseases has been increasing in Shanghai, China. Our findings provide useful information for the projection of growing burden of T2DM and hypertension in Chinese adults.

Keywords: type 2 diabetes; hypertension; prevalence; body mass index; waist circumference

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Article summary

Article focus

- The shift in BMI and WC among Chinese adults over past one decade.
- The contribution of changes in overall and central obesity to the increasing burden of chronic disease in China.

Key messages

- The WC increased in Chinese adults over the decade spanning 2002-2009, while BMI did not change over the same period.
- BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM in Chinese adults.
- Our findings provide useful information for the projection of a more rapidly growing burden of T2DM than hypertension in Chinese adults.

Strengths and limitations of this study

- The strengths of this study include the strict process of multistage sampling in adult population of Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.
- The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM.
- The differences in several demographic characteristics between the participants of the two surveys indicate the possibility of selection bias.

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Introduction

A rising worldwide prevalence of chronic disease, manifested primarily as hypertension and type 2 diabetes (T2DM), has been well documented [1-4]. In Chinese aged 15-74 years old, the prevalence of hypertension increased from 5.11% in 1959, 7.73% in 1979 [5] and 13.58% in 1991[6] to 17.65% in 2002 [7]. The prevalence of T2DM tripled between 1980 (about 1.0%) and 1996 (3.2%) [8 9], and reached 9.7% in 2008 among adults at 20 years old or above [10]. It is estimated that over 92 million people in China have T2DM. This represents approximately half of the world's diabetic population, and places China at the "global epicenter of the diabetes epidemic" [4].

Both hypertension and T2DM are associated with obesity [11 12]. Obesity is often measured by body mass index (BMI). Across the entire range of BMI, the risk of hypertension and T2DM increases, making a higher BMI a strong predictor of both hypertension and T2DM [4 12-14]. However, a significant proportion of Asian adults diagnosed with T2DM are with the normal BMI, ie.18.5-25.0 kg/m^2 [15 16]. BMI is a general indicator of overt obesity, but does not give information about the distribution of obesity. Central obesity, often assessed via waist circumference (WC), is also strongly correlated with T2DM in both European and Asian adults [11 17]. While changes in BMI have been well documented in China over past several decades [2 18], changes in WC, and thus central obesity, are not well described.

In this study, we took advantage of the data from population based cross-sectional surveys conducted in Shanghai in 2002-03 and in 2009. We used the data from the two surveys to evaluate correlations between shifts in BMI and WC with the prevalence of hypertension and T2DM in Chinese adults. Our results may help to better understand the contribution of overall obesity and central obesity in the increasing burden of chronic disease in China.

Materials and Methods

Study Participants

A representative sample of the general population was randomly selected through a multistage sampling process in the 2002-03 survey. Firstly, 4 districts and 2 counties were randomly selected

from a total of 12 districts and 7 counties in Shanghai, China. And then, 1-2 sub-districts or towns were randomly selected from each selected district or county. Next, 1-2 communities or villages, usually 1,000-2,000 residents for each, were randomly selected from each selected sub-district or town. Finally, eligible subjects (permanent residents of Shanghai, 15-74 years old and having been in the city for at least 5 years) were randomly selected from the selected communities and villages and were invited for participation. Pregnant women, individuals with type I diabetes, and physically or mentally disabled persons were excluded from the participation. During the period of May 2002-October 2003, a total of 17,526 eligible subjects were recruited, and 14,401 (82.17%) participated the survey.

The 2009 survey used the similar sampling method except that only 7 communities and villages were randomly selected in the third stage of sampling. The inclusion and exclusion criteria of the 2009 survey were also similar to those for the 2002-03 survey, except that only those at the age of 35-74 years old were eligible for the 2009 survey. Among 7,627 eligible adults contacted during the period of May-July 2009, 7,414 (97.21%) were interviewed and donated blood samples.

To make the two surveys comparable, we excluded 1,071 subjects younger than 35 years from the 2002-03 survey. After further excluding subjects with missing information, the final analysis included 5,050 men and 7,279 women in the 2002-03 survey and 3,461 men and 3,962 women in the 2009 survey. The Institutional Review Board at Shanghai Municipal Center of Disease Control and Prevention approved the study. Informed consent was obtained from each participant before data collection.

Data Collection

A similar survey approach was followed by the two investigations. In both surveys, information on demographic and socioeconomic factors, diagnosis of diabetes, tobacco and alcohol use, physical activity and family history of diabetes was collected by trained interviewers with a structured questionnaire at community clinics located in the residential areas of the participants.

At the interview, each participant's blood pressure, body weight, standing height, and waist

circumference (WC) were measured by trained staff. Blood pressure was measured on the right arm in the sitting position using standard mercury sphygmomanometer after at least 5 minutes of rest. The first and fifth Korotkoff sounds were recorded. Body weight and height were recorded while the subject was in light clothing and without shoes. Body weight was measured with electronic scales to the nearest 0.1 kg. Body height was measured to the nearest 0.1 cm by using a stadiometer. WC, recorded to the nearest 0.1 cm, was taken with a cloth tape and was measured on bare skin at the midline between the lower border of the ribs and the iliac crest in the horizontal plane after a normal expiration. Two measurements were taken and the mean of the replicates was used in the following analyses. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2) using the direct measurements.

Laboratory Measurements

After at least 10 hours of overnight fasting, 1-1.5 ml venous blood specimen was collected in a vacuum tube containing sodium fluoride. All participants with no history of diabetes and having a fasting plasma glucose level of < 7.0 mmol per liter (mmol/l) were then asked to have an oral glucose-tolerance test (OGTT). Blood samples were drawn at 0 and 120 minutes after a standard 75 gram glucose load. Plasma glucose was measured with Glucose oxidase-peroxidase (GOD-PAP) method.

Diagnosis of T2DM and Hypertension

Previously diagnosed T2DM and hypertension was identified by a positive response from the participant to the question of "Have you ever diagnosed with T2DM/hypertension by a doctor?" and confirmed by medical records in which prescriptions of anti-hypertensive or hypoglycemic medications were presented. The consistent rate was 100%. For those who had a negative response, the T2DM was diagnosed with measured glucose level by using the 1999 World Health Organization diagnostic criteria [Department of Noncommunicable Disease Surveillance. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1. Diagnosis and classification of diabetes mellitus. Geneva: World Health

Organization, 1999. (Accessed July 5, 2010, at http://www.staff.ncl.ac.uk/philip.home/who_dmg.pdf.)] and hypertension referred to the subjects with measured systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg and confirmed by clinical visits. Total T2DM and hypertension included both previously diagnosed and newly-diagnosed patients. 42.7% (1,110 of 2,598) diabetic patients and 10.3% (694 of 6,735) hypertensive patients were newly-diagnosed in the two surveys.

Statistical Analysis

SAS software 9.2 was used for all the statistical analyses. Characteristics of the subgroups were described using summary statistics (median, 25^{th} and 75^{th} percentile, frequencies, and percentages) separately for men and women. The differences between two surveys were compared using χ^2 test (category variables) and Wilcoxon tests (continuous variables). The annual percentage changes (APC) in prevalence between two surveys were calculated as (prevalence in 2009 – prevalence in 2002-03) / number of years using logarithms for each age group. Percentile curves were constructed for BMI and WC values in the two surveys by gender using the LMS (lambda, mu, sigma) method. Restricted cubic splines (RCS) were used to model a potential curvilinear relationship of BMI and WC with hypertension and diabetes using the 5^{th}, 25^{th}, 75^{th} and 95^{th} percentiles as fixed knots and the 50^{th} percentile as the reference. Polynomial logistic regression were used to estimate the odds ratios (OR) and 95% confidence intervals (95% CI) of BMI and WC with T2DM and hypertension. Meta-analysis was applied to obtain the combined ORs and 95% CI considering the potential heterogeneity of the populations in the two surveys. The residual method was used to derive the independent effect of BMI and WC with each other in the models. *P* value less than 0.05 was considered as a test of significance based on two sides.

Results

The male participants in two surveys were similar in age, resident site and cigarette smoking while the females were comparable in cigarette smoking ($P > 0.05$) (Table 1). Compared to the subjects in 2002-03 survey, the participants of 2009 survey, both men and women, had lower level

of education, higher level of income per capita, more prior history of T2DM, higher frequency of alcohol drinking and lower frequency of leisure time activity, and were more likely to have a family history of diabetes.

Figure 1 shows the shapes of the BMI and WC distribution curves among men and women changed over the period of the two surveys. After adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, and family history of T2DM, the curves of BMI were almost overlapped in both men and women. However, the WC curves for men and women were shifted to the right between 2002-03 and 2009, with the mean WC increasing from 83.6 to 85.3 cm for men and from 78.4 to 80.6 cm for women.

As presented in table 2, the prevalence of obesity, both overall and central, increased with increasing age groups. While the prevalence of overall obesity (BMI $\geq$ 28 kg/m^2) did not changed between two surveys (all P values > 0.05), the prevalence of central obesity were significantly higher in 2009 survey in each age group (all P values < 0.001). A more pronounced increase in prevalence of central obesity and T2DM was observed among subjects aged 45-49 years old in both men and women; whereas the change in prevalence of hypertension between two surveys appeared more evident in older men and younger women over the period. Using the World Health Organization (WHO) criteria for obesity did not change the results substantially (data not shown in the tables).

BMI and WC were highly correlated with each other, with a correlation coefficient of 0.77 (P < 0.0001) among men and 0.78 (P < 0.0001) among women after adjusting for age. Therefore, the residual method was used to test the potential respective non-linear relationships of BMI and WC with the risk of T2DM and hypertension (Figure 2). The dose-response analysis likewise showed a statistically significant increased risk of T2DM at high level of WC and a significant elevated risk of hypertension at high level of BMI in both men and women after adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, family history of T2DM and phase of surveys, with P values for non-linear relationship tests < 0.05. No significant relationship was

observed between BMI and T2DM in men and between WC and hypertension in women.

As shown in table 3, in both sexes, BMI adjusted for WC (residuals) appeared more strongly associated with hypertension while WC adjusted for BMI (residuals) was more evidently related with T2DM. Comparing with the lowest quartile of BMI residuals, the risk of hypertension increased 85% (95%CI: 1.59-2.15) in men and 1.23-fold (95%CI: 1.94-2.57) in women, whereas the risk of T2DM did not increase significantly in both sexes. On the other hand, the ORs of the highest versus the lowest quartile WC residuals for T2DM were 1.75 (95%CI: 1.33-2.30) in men and 2.37 (95%CI: 1.78-3.15) in women, higher than the OR of 1.57 (95%CI: 1.35-1.82) in men and 1.13 (95%CI: 0.98-1.30) in women for hypertension.

We further evaluated the potential joint effect of BMI and WC on T2DM and hypertension (table 4). The participants were classified into normal weight (BMI 18.5-23.9 kg/m^2), overweight (24.0-27.9 kg/m^2), or obese ($\geq$ 28 kg/m^2) based on data from Chinese adults, and were defined as with normal or increased WC using sex-specific cut-offs (85 cm in men and 80 cm in women) [19]. The risk of T2DM and hypertension increased across groups defined by BMI and WC, with the highest risk observed among men with the lowest BMI but a higher WC, and among those with the highest BMI and a higher WC for hypertension. However, no significant interaction was observed between BMI and WC (all *P* values for interaction tests > 0.05).

Discussion

In this representative sample of the adult population in Shanghai, the largest city in China, we observed an increased prevalence of central obesity, hypertension and T2DM over the decade spanning 2002-2009. In contrast, BMI did not change over the same period. Our results present a snapshot of overt versus central obesity in the Chinese population and suggest that the epidemic of central obesity in this population, which has been more closely associated with the prevalence of T2DM, may lead to a more rapidly growing burden of T2DM in China.

Chinese adults have lower rates of overweight and obesity than their Western counterparts using the WHO criteria (BMI $\geq$ 25 kg/m^2 for overweight and BMI $\geq$ 30 kg/m^2 for obesity) [15 16].

Nevertheless, increasing trends of BMI in Chinese adults have been well documented [18 20]. In two national nutritional surveys undertaken in 1982 and 1992 in China, the prevalence of overweight/obesity (BMI ≥ 25 kg/m^2) in subjects 20-70 years of age was 10% and 15%, respectively. Between 1992 and 2002, the combined prevalence of overweight and obesity increased from 14.6 to 21.8% [21]. Interestingly, the increase in BMI among Chinese adults has slowed down during past decades [2]. In this study, we did not observe an increase in BMI and prevalence of obesity defined by the Chinese obesity standards or by WHO criteria (data not shown). Instead, we observed a significant increase in WC, a measure of central obesity between surveys. Our observation of increased WC in Chinese adults, without a concomitant increase in BMI, represents an increasing burden of central obesity in this population. The increase in central obesity indicates an upward trend in body fat percentages in the population who have been previously observed with higher body fat percentages compared to other ethnic people with the same BMI [22 23].

Both epidemic of overall and central obesity parallels a continuously increasing prevalence of hypertension and T2DM in China [21]. Several studies indicate that overall obesity (BMI) is more strongly associated with hypertension, while central obesity (WC) is more strongly associated with T2DM [17 24-26]. The rationale for these associations is based on the notion that central obesity reflects specific accumulation of visceral adipose tissue. Excess visceral adipose tissue is metabolically unfavorable due to productions of free fatty acids and inflammatory mediators. Overall obesity, on the other hand, represents a greater overall physiologic strain and effects vascular and cardiac parameters more significantly. In this study, we observed a significant increase in prevalence of T2DM regardless of gender or age groups, which was more pronounced than the change in the prevalence of hypertension during the period of 2002-03 and 2009. We also observed a closer association of central obesity with the prevalence of T2DM than with the prevalence of hypertension. These results support the notion that central obesity in particular is a stronger risk factor for T2DM than for hypertension in Chinese adults. Due to the cross-sectional design, however, our study was unable to make a causal inference.

The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM. The differences in several demographic characteristics between the participants of the two surveys indicate the changes in general population over time. However, selection bias could not be excluded. However, there are several strengths, including the strict process of multistage sampling in adult population in Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.

Conclusions

In summary, this study describes the potential association of central obesity with an upward trend of T2DM, implicating a more rapidly growing burden of T2DM than hypertension in Chinese adults. The findings in Shanghai, the largest city and one of the most economically developed areas in China, provide useful information for the projection of future trends in the whole country.

Acknowledgements

We thank Dr. Xiao-ou Shu and Dr. Hui Cai of Vanderbilt University for their contributions in study design and data analysis. The authors thank the study participants of the two cross-sectional surveys and the healthcare workers in each community involved.

Footnotes

Contributors YR and MM contributed to data collection, data analysis and draft of the paper. YR, YYL, QDY, and LS contributed to data collection and quality control. LJM contributed to revision of the paper. HZ contributed to data clean and analysis. RL and WHX contributed to study design, statistical analysis and revision of the paper. All authors contributed to the interpretation of data and revision of the manuscript. All authors approved the final version.

Funding This study was supported by the Key Program of Shanghai Municipal Committee of Science and Technology (04 DZ19502), the Shanghai Medical Development Program (01ZD001) and the Shanghai Municipal Health Bureau (GWDTR201204). W. H. Xu was supported by a training grant from the Fogarty International Center (D43 TW008313 to X. O. Shu). The funders had no role in study design, data collection or analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest: None declared.

Data sharing: No additional unpublished data.

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Figure 1. Shift in BMI and WC over the period of the two population-based surveys

Figure 2. Non-linear dose-response relationship of BMI and WC with hypertension and T2DM among participants of the two population-based surveys

Table 1. Characteristics of participants in two population-based surveys in Shanghai, China

Characteristics	1st survey		2nd survey		*P-value between surveys* [a]	
	Men (N=5,050)	Women (N=7,279)	Men (N=3,461)	Women (N=3,962)	*In men*	*In women*
Age (yrs., mean ± SD)	54.8 ± 10.8	53.1 ± 10.3	54.7 ± 9.5	54.7 ± 9.1	0.55	<0.0001
Resident site (%)						
Urban	71.1	63.0	72.4	72.0		
Rural	29.0	37.0	27.7	28.0	*0.19*	*<0.0001*
Education (%)						
No formal education	4.1	18.4	3.2	9.5		
Primary school	18.2	23.0	14.7	17.7		
Middle school	35.3	31.1	45.7	45.2		
High school	27.6	22.6	27.6	23.8		
Colleague or above	14.8	4.9	8.8	3.9	*0.0025*	*<0.0001*
Per capita income (yuan/mo.) (%)						
<1000	37.0	45.5	4.9	4.0		
1000-2999	38.3	38.4	41.8	46.7		
3000-5000	22.5	17.9	33.2	33.3		
>5000	2.2	1.3	20.0	16.0	*<0.0001*	*<0.0001*
Family history of type 2diabetes	12.3	13.1	16.4	19.0	*<0.0001*	*<0.0001*
Prevalence of type 2diabetes (%)	13.6	10.3	17.4	14.1	*<0.0001*	*<0.0001*
Prevalence of hypertension (%)	34.8	28.3	41.8	37.1	*<0.0001*	*<0.0001*
Cigarette smoking (%)	61.4	1.7	62.6	1.8	*0.22*	*0.93*
Alcohol drinking (%)	40.4	2.4	54.0	5.0	*<0.0001*	*<0.0001*
Leisure-time activity (%)	13.3	13.1	10.8	9.0	*0.0009*	*<0.0001*

[a] *P* for Wilcoxon tests or chi-square tests

Table 2. Prevalence of obesity, hypertension and type 2 diabetes in participants of the two population-based surveys by age groups in Shanghai, China

	No. of subjects		Overall Obesity		*APC*	Central obesity		*APC*	Hypertension		*APC*	Type 2 diabetes		*APC*
	1[st] survey	2[nd] survey	1[st] survey	2[nd] survey	*(%)*	1[st] survey	2[nd] survey	*(%)*	1[st] survey	2[nd] survey	*(%)*	1[st] survey	2[nd] survey	*(%)*
Men														
Overall	5050	3461	11.7	11.9	*0.21*	46.3	53.8	*2.35*	34.8	41.8	*2.87*	13.6	17.4	*3.78*
Age-groups														
35-	414	230	10.5	9.1	*-2.11*	41.8	45.2	*1.22*	15.2	11.7	*-3.92*	4.6	5.7	*3.25*
40-	574	302	10.0	8.3	*-2.83*	41.8	47.00	*1.85*	22.5	21.9	*-0.43*	7.8	7.6	*-0.44*
45-	837	445	12.6	12.6	*-0.04*	44.0	53.7	*3.12*	25.3	31.0	*3.16*	7.8	13.7	*9.13*
50-	833	739	12.2	10.8	*-1.76*	44.1	53.8	*3.12*	33.1	40.3	*3.07*	12.7	18.3	*5.72*
55-	628	669	10.4	13.2	*3.78*	47.3	54.6	*2.25*	35.4	45.6	*3.99*	15.0	17.9	*2.82*
60-	507	513	10.5	15.4	*6.18*	48.7	56.1	*2.19*	44.6	51.7	*2.29*	15.6	20.1	*3.98*
65-	674	313	12.6	11.8	*-0.99*	51.4	61.0	*2.67*	49.4	59.4	*2.88*	20.8	26.2	*3.64*
70-	583	250	13.8	9.6	*-5.40*	51.1	54.0	*0.85*	50.9	65.2	*3.87*	24.2	25.6	*0.88*
Women														
Overall	7279	3962	13.8	13.8	*0.02*	41.7	54.2	*4.10*	28.3	37.1	*4.28*	10.3	14.1	*4.84*
Age-groups														
35-	615	251	7.5	7.2	*-0.65*	22.6	26.3	*2.35*	6.8	10.8	*7.24*	3.3	4.0	*3.17*
40-	1000	287	9.4	11.2	*2.66*	27.6	38.0	*5.05*	11.7	15.7	*4.61*	4.1	5.9	*5.81*
45-	1491	563	11.0	9.8	*-1.82*	32.3	42.6	*4.38*	19.3	23.5	*3.03*	5.8	8.7	*6.32*
50-	1309	866	15.1	14.1	*-1.00*	43.9	54.0	*3.24*	28.7	31.0	*1.16*	8.3	9.4	*1.94*
55-	838	818	15.7	13.6	*-2.17*	47.5	60.6	*3.83*	33.9	39.7	*2.48*	8.8	15.3	*8.80*
60-	610	585	19.2	18.1	*-0.87*	53.5	63.1	*2.58*	40.5	52.8	*4.17*	16.7	19.2	*2.11*
65-	799	327	18.0	18.4	*0.28*	59.0	66.1	*1.76*	48.4	59.3	*3.17*	23.7	27.8	*2.54*
70-	617	265	18.2	16.6	*-1.36*	60.2	68.7	*2.05*	51.4	64.5	*3.57*	21.4	27.2	*3.75*
All subjects														
Overall	12329	7423	13.0	12.9	*-0.05*	43.6	54.0	*3.35*	31.0	39.3	*3.75*	11.7	15.6	*4.53*
Age-groups [a]														
35-	1029	481	8.7	8.0	*-1.04*	30.3	33.9	*2.39*	10.2	11.2	*1.49*	3.8	4.7	*3.63*
40-	1574	589	9.6	10.1	*0.11*	32.7	41.3	*4.14*	15.6	17.9	*2.92*	5.5	6.5	*3.41*
45-	2328	1008	11.6	10.8	*-0.77*	36.5	46.6	*4.16*	21.5	26.2	*3.46*	6.5	10.5	*8.22*
50-	2142	1605	13.9	12.8	*-1.53*	44.0	53.9	*3.19*	30.4	34.6	*0.90*	10.0	12.8	*4.69*
55-	1466	1487	13.4	13.4	*0.01*	47.4	58.1	*3.13*	34.5	42.2	*3.20*	11.5	16.4	*5.75*
60-	1117	1098	15.2	16.9	*1.59*	51.3	59.9	*2.39*	42.4	52.3	*3.29*	16.2	19.6	*2.96*
65-	1473	640	15.6	15.4	*-0.39*	55.5	63.8	*2.11*	48.9	59.4	*3.04*	22.3	27.1	*2.98*
70-	1200	515	16.0	13.2	*-2.94*	55.8	61.5	*1.52*	51.2	64.9	*3.71*	22.8	26.4	*2.32*

[a] adjusted for sex according to the distribution in the first survey.

Table 3. Association of body size with hypertension and type 2 diabetes in two population-based surveys in Shanghai, China

	No. of subjects with neither diseases	Type 2 diabetes only		Hypertension only		Both	
		N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
BMI residuals							
Men							
Q1	1260	156	1.00	529	1.00	175	1.00
Q2	1224	142	0.99 (0.77, 1.27)	583	1.16 (1.00, 1.34)	172	1.11(0.87, 1.41)
Q3	1164	132	1.09 (0.84, 1.41)	651	1.50 (1.29, 1.74)	171	1.36(1.07, 1.73)
Q4	1079	123	1.16 (0.88, 1.51)	709	1.85 (1.59, 2.15)	207	1.95(1.54, 2.47)
	P for trend		*0.2472*		*<0.0001*		*<0.0001*
Women							
Q1	1816	166	1.00	600	1.00	223	1.00
Q2	1866	148	1.02 (0.80, 1.29)	629	1.29 (1.12, 1.48)	162	0.96(0.77, 1.21)
Q3	1835	125	0.89 (0.69, 1.15)	687	1.51 (1.31, 1.73)	158	1.03(0.82, 1.31)
Q4	1634	109	0.94 (0.73, 1.23)	847	2.23 (1.94, 2.57)	215	1.85(1.15, 2.98)
	P for trend		*0.4864*		*<0.0001*		*0.0067*
All subjects							
Q1	3048	330	1.00	1162	1.00	385	1.00
Q2	3079	282	1.00 (0.84, 1.19)	1200	1.22 (1.11, 1.35)	363	1.03(0.87, 1.22)
Q3	2998	278	0.98 (0.82, 1.18)	1346	1.50 (1.36, 1.67)	302	1.18(1.00, 1.40)
Q4	2753	211	1.04 (0.86, 1.26)	1527	2.05 (1.85, 2.27)	433	1.88(1.60, 2.21)
	P for trend		0.2280		*<0.0001*		*<0.0001*
WC residuals							
Men							
Q1	1376	102	1.00	531	1.00	111	1.00
Q2	1232	131	1.34 (1.02, 1.78)	601	1.23 (1.06, 1.42)	155	1.41(1.07, 1.84)
Q3	1130	148	1.39 (0.70, 2.77)	644	1.39 (1.20, 1.62)	197	1.73(1.33, 2.25)
Q4	989	172	1.75 (1.33, 2.30)	696	1.57 (1.35, 1.82)	262	2.25(1.74, 2.90)
	P for trend		*<0.0001*		*<0.0001*		*<0.0001*
Women							
Q1	2019	80	1.00	598	1.00	108	1.00
Q2	1935	102	1.17 (0.86, 1.59)	651	1.04 (0.91, 1.18)	117	0.94(0.71, 1.25)
Q3	1708	172	2.04 (1.54, 2.70)	732	1.14 (0.99, 1.30)	194	1.40(1.08,1.82)
Q4	1489	194	2.37 (1.78, 3.15)	782	1.13 (0.98, 1.30)	339	2.06(1.26, 3.38)
	P for trend		*<0.0001*		*0.0216*		*<0.0001*
All subjects							
Q1	3453	161	1.00	1109	1.00	203	1.00
Q2	3192	260	1.26 (0.99, 1.60)	1211	1.12 (1.01, 1.23)	260	1.16(0.82, 1.62)
Q3	2838	301	1.66 (1.16, 2.36)	1373	1.25 (1.13, 1.38)	412	1.55(1.29, 1.87)
Q4	2395	379	2.03 (1.66, 2.47)	1542	1.34 (1.09, 1.64)	608	2.18(1.83, 2.61)
	P for trend		*0.0001*		*0.0021*		*<0.0001*

Missing value excluded from the analysis.
OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), phase of study (first /second survey); Additionally adjusted for sex (male/female) for all subjects.

Table 4. Joint effect of general obesity and central obesity on type 2 diabetes among Chinese adults

BMI	WC：Lower			WC: Higher			OR (95%CI) for hypertension		OR (95%CI) for type 2 diabetes	
	No. of subjects	Hypertension N (%)	Diabetes N (%)	No. of subjects	Hypertension N (%)	Diabetes N (%)	WC: Lower	WC: Higher	WC: Lower	WC: Higher
Men										
<18.5	212	36	20	16	10	6	0.61(0.42, 0.89)	3.68(1.28, 10.59)	1.02(0.62, 1.67)	3.77(1.13, 12.56)
18.5-23.9	3034	767	296	679	249	111	1.00	1.56(0.94, 2.57)	1.00	1.48(1.15, 1.90)
24.0-27.9	1010	356	134	2530	1179	483	1.61(1.13, 2.32)	2.38(1.78, 3.17)	1.46(1.16, 1.83)	1.85(1.16, 2.96)
⩾28.0	36	20	4	960	580	224	3.91(1.95, 7.82)	4.67(3.97, 5.49)	1.71(0.55, 5.37)	2.60(2.12, 3.18)
						P for interaction	*0.0711*		*0.0933*	
Women										
<18.5	313	51	19	8	2	1	0.68(0.49, 0.94)	0.85(0.16, 4.51)	0.93(0.56, 1.54)	2.45(0.22, 26.72)
18.5-23.9	4323	821	265	974	314	165	1.00	1.48(1.26, 1.75)	1.00	2.36(1.89, 2.94)
24.0-27.9	1330	384	93	2724	1102	437	1.84(1.59, 2.14)	2.21(1.97, 2.49)	1.19(0.92, 1.53)	2.14(1.81, 2.54)
≥28.0	81	32	9	1467	815	317	3.10(1.93, 5.00)	4.33(3.77, 4.96)	2.14(1.01, 4.52)	3.08(2.56, 3.71)
						P for interaction	*0.3524*		*0.4011*	
Total										
<18.5	525	87	39	24	12	7	0.65(0.51, 0.83)	2.25(0.85, 5.93)	0.97(0.68, 1.39)	3.45(1.18, 10.12)
18.5-23.9	7357	1588	561	1653	563	276	1.00	1.52(1.25, 1.85)	1.00	1.88(1.42, 2.49)
24.0-27.9	2340	740	227	5254	2281	920	1.74(1.50, 2.03)	2.31(2.03, 2.62)	1.33(1.12, 1.58)	1.99(1.62, 2.45)
⩾28.0	117	5	13	2427	1395	541	3.34(2.26, 4.94)	4.46(4.02, 4.96)	2.00(1.07, 3.74)	2.85(2.49, 3.27)
						P for interaction	*0.0562*		*0.0798*	

Higher WC defined as ≥ 85 cm for men and ≥ 80 cm for women

OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), and phase of study (first /second survey).

Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

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RUNNING HEADER: Obesity and prevalence of hypertension and T2DM in Chinese adults

Word Count:

Abstract: 249

Text: 2,658

Abstract:

Objective: To evaluate the changes in body mass index (BMI) and waist circumference (WC) and their associations with the prevalence of hypertension and type 2 diabetes (T2DM) in Chinese adults.

Design: Two consecutive population-based cross-sectional surveys.

Setting: A total of 12 districts and 7 counties in Shanghai, China.

Participants: 12,329 randomly selected participants of the survey in 2002-2003, and 7,423 randomly selected participants of the survey in 2009. All subjects were residents of Shanghai aged 35-74 years old.

Outcome measures: Measured BMI and WC. Previously-diagnosed and newly-identified hypertension and T2DM by measured blood pressure, fasting and post-load glucose.

Results: While the participants of the two surveys were comparable in BMI in each age group, the participants of the 2009 survey had significantly larger WC than those of the 2002-03 survey, with an annual percentage change (APC) being higher among subjects aged 45-49 years old in both men and women. The increase in prevalence of T2DM was observed in all age groups and also appeared more evident in subjects aged 45-49 years old. The prevalence of hypertension was observed to increase more rapidly in elderly men and middle-aged women. Obesity, both overt and central, was associated with the risk of the two diseases, but BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM.

Conclusion: The prevalence of central obesity and related chronic diseases has been increasing in Shanghai, China. Our findings provide useful information for the projection of growing burden of T2DM and hypertension in Chinese adults**.**

Keywords: type 2 diabetes; hypertension; prevalence; body mass index; waist circumference

Article summary

Article focus

- The shift in BMI and WC among Chinese adults over past one decade.
- The contribution of changes in overall and central obesity to the increasing burden of chronic disease in China.

Key messages

- The WC increased in Chinese adults over the decade spanning 2002-2009, while BMI did not change over the same period.
- BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM in Chinese adults.
- Our findings provide useful information for the projection of a more rapidly growing burden of T2DM than hypertension in Chinese adults.

Strengths and limitations of this study

- The strengths of this study include the strict process of multistage sampling in adult population of Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.
- The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM.
- The differences in several demographic characteristics between the participants of the two surveys indicate the possibility of selection bias.

Introduction

A rising worldwide prevalence of chronic disease, manifested primarily as hypertension and type 2 diabetes (T2DM), has been well documented [1-4]. In Chinese aged 15-74 years old, the prevalence of hypertension increased from 5.11% in 1959, 7.73% in 1979 [5] and 13.58% in 1991[6] to 17.65% in 2002 [7]. The prevalence of T2DM tripled between 1980 (about 1.0%) and 1996 (3.2%) [8 9], and reached 9.7% in 2008 among adults at 20 years old or above [10]. It is estimated that over 92 million people in China have T2DM. This represents approximately half of the world's diabetic population, and places China at the "global epicenter of the diabetes epidemic" [4].

Both hypertension and T2DM are associated with obesity [11 12]. Obesity is often measured by body mass index (BMI). Across the entire range of BMI, the risk of hypertension and T2DM increases, making a higher BMI a strong predictor of both hypertension and T2DM [4 12-14]. However, a significant proportion of Asian adults diagnosed with T2DM are with the normal BMI, ie.18.5-25.0 kg/m^2 [15 16]. BMI is a general indicator of overt obesity, but does not give information about the distribution of obesity. Central obesity, often assessed via waist circumference (WC), is also strongly correlated with T2DM in both European and Asian adults [11 17]. While changes in BMI have been well documented in China over past several decades [2 18], changes in WC, and thus central obesity, are not well described.

In this study, we took advantage of the data from population based cross-sectional surveys conducted in Shanghai in 2002-03 and in 2009. We used the data from the two surveys to evaluate correlations between shifts in BMI and WC with the prevalence of hypertension and T2DM in Chinese adults. Our results may help to better understand the contribution of overall obesity and central obesity in the increasing burden of chronic disease in China.

Materials and Methods

Study Participants

A representative sample of the general population was randomly selected through a multistage sampling process in the 2002-03 survey. Firstly, 4 districts and 2 counties were randomly selected

from a total of 12 districts and 7 counties in Shanghai, China. And then, 1-2 sub-districts or towns were randomly selected from each selected district or county. Next, 1-2 communities or villages, usually 1,000-2,000 residents for each, were randomly selected from each selected sub-district or town. Finally, eligible subjects (permanent residents of Shanghai, 15-74 years old and having been in the city for at least 5 years) were randomly selected from the selected communities and villages and were invited for participation. Pregnant women, individuals with type I diabetes, and physically or mentally disabled persons were excluded from the participation. During the period of May 2002-October 2003, a total of 17,526 eligible subjects were recruited, and 14,401 (82.17%) participated the survey.

The 2009 survey used the similar sampling method except that only 7 communities and villages were randomly selected in the third stage of sampling. The inclusion and exclusion criteria of the 2009 survey were also similar to those for the 2002-03 survey, except that only those at the age of 35-74 years old were eligible for the 2009 survey. Among 7,627 eligible adults contacted during the period of May-July 2009, 7,414 (97.21%) were interviewed and donated blood samples.

To make the two surveys comparable, we excluded 1,071 subjects younger than 35 years from the 2002-03 survey. After further excluding subjects with missing information, the final analysis included 5,050 men and 7,279 women in the 2002-03 survey and 3,461 men and 3,962 women in the 2009 survey. The Institutional Review Board at Shanghai Municipal Center of Disease Control and Prevention approved the study. Informed consent was obtained from each participant before data collection.

Data Collection

A similar survey approach was followed by the two investigations. In both surveys, information on demographic and socioeconomic factors, diagnosis of diabetes, tobacco and alcohol use, physical activity and family history of diabetes was collected by trained interviewers with a structured questionnaire at community clinics located in the residential areas of the participants.

At the interview, each participant’s blood pressure, body weight, standing height, and waist

circumference (WC) were measured by trained staff. Blood pressure was measured on the right arm in the sitting position using standard mercury sphygmomanometer after at least 5 minutes of rest. The first and fifth Korotkoff sounds were recorded. Body weight and height were recorded while the subject was in light clothing and without shoes. Body weight was measured with electronic scales to the nearest 0.1 kg. Body height was measured to the nearest 0.1 cm by using a stadiometer. WC, recorded to the nearest 0.1 cm, was taken with a cloth tape and was measured on bare skin at the midline between the lower border of the ribs and the iliac crest in the horizontal plane after a normal expiration. Two measurements were taken and the mean of the replicates was used in the following analyses. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2) using the direct measurements.

Laboratory Measurements

After at least 10 hours of overnight fasting, 1-1.5 ml venous blood specimen was collected in a vacuum tube containing sodium fluoride. All participants with no history of diabetes and having a fasting plasma glucose level of < 7.0 mmol per liter (mmol/l) were then asked to have an oral glucose-tolerance test (OGTT). Blood samples were drawn at 0 and 120 minutes after a standard 75 gram glucose load. Plasma glucose was measured with Glucose oxidase-peroxidase (GOD-PAP) method.

Diagnosis of T2DM and Hypertension

Previously diagnosed T2DM and hypertension was identified by a positive response from the participant to the question of "Have you ever diagnosed with T2DM/hypertension by a doctor?" and confirmed by medical records in which prescriptions of anti-hypertensive or hypoglycemic medications were presented. The consistent rate was 100%. For those who had a negative response, the T2DM was diagnosed with measured glucose level by using the 1999 World Health Organization diagnostic criteria [Department of Noncommunicable Disease Surveillance. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1. Diagnosis and classification of diabetes mellitus. Geneva: World Health

Organization, 1999. (Accessed July 5, 2010, at http://www.staff.ncl.ac.uk/philip.home/who_dmg.pdf.)] and hypertension referred to the subjects with measured systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg and confirmed by clinical visits. Total T2DM and hypertension included both previously diagnosed and newly-diagnosed patients. 42.7% (1,110 of 2,598) diabetic patients and 10.3% (694 of 6,735) hypertensive patients were newly-diagnosed in the two surveys.

Statistical Analysis

SAS software 9.2 was used for all the statistical analyses. Characteristics of the subgroups were described using summary statistics (median, 25^{th} and 75^{th} percentile, frequencies, and percentages) separately for men and women. The differences between two surveys were compared using χ^2 test (category variables) and Wilcoxon tests (continuous variables). The annual percentage changes (APC) in prevalence between two surveys were calculated as (prevalence in 2009 – prevalence in 2002-03) / number of years using logarithms for each age group. Percentile curves were constructed for BMI and WC values in the two surveys by gender using the LMS (lambda, mu, sigma) method. Restricted cubic splines (RCS) were used to model a potential curvilinear relationship of BMI and WC with hypertension and diabetes using the 5^{th}, 25^{th}, 75^{th} and 95^{th} percentiles as fixed knots and the 50^{th} percentile as the reference. Polynomial logistic regression were used to estimate the odds ratios (OR) and 95% confidence intervals (95% CI) of BMI and WC with T2DM and hypertension. Meta-analysis was applied to obtain the combined ORs and 95% CI considering the potential heterogeneity of the populations in the two surveys. The residual method was used to derive the independent effect of BMI and WC with each other in the models. *P* value less than 0.05 was considered as a test of significance based on two sides.

Results

The male participants in two surveys were similar in age, resident site and cigarette smoking while the females were comparable in cigarette smoking ($P > 0.05$) (Table 1). Compared to the subjects in 2002-03 survey, the participants of 2009 survey, both men and women, had lower level

of education, higher level of income per capita, more prior history of T2DM, higher frequency of alcohol drinking and lower frequency of leisure time activity, and were more likely to have a family history of diabetes.

Figure 1 shows the shapes of the BMI and WC distribution curves among men and women changed over the period of the two surveys. After adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, and family history of T2DM, the curves of BMI were almost overlapped in both men and women. However, the WC curves for men and women were shifted to the right between 2002-03 and 2009, with the mean WC increasing from 83.6 to 85.3 cm for men and from 78.4 to 80.6 cm for women.

As presented in table 2, the prevalence of obesity, both overall and central, increased with increasing age groups. While the prevalence of overall obesity (BMI $\geq$ 28 kg/m^2) did not changed between two surveys (all P values > 0.05), the prevalence of central obesity were significantly higher in 2009 survey in each age group (all P values < 0.001). A more pronounced increase in prevalence of central obesity and T2DM was observed among subjects aged 45-49 years old in both men and women; whereas the change in prevalence of hypertension between two surveys appeared more evident in older men and younger women over the period. Using the World Health Organization (WHO) criteria for obesity did not change the results substantially (data not shown in the tables).

BMI and WC were highly correlated with each other, with a correlation coefficient of 0.77 (P < 0.0001) among men and 0.78 (P < 0.0001) among women after adjusting for age. Therefore, the residual method was used to test the potential respective non-linear relationships of BMI and WC with the risk of T2DM and hypertension (Figure 2). The dose-response analysis likewise showed a statistically significant increased risk of T2DM at high level of WC and a significant elevated risk of hypertension at high level of BMI in both men and women after adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, family history of T2DM and phase of surveys, with P values for non-linear relationship tests < 0.05. No significant relationship was

observed between BMI and T2DM in men and between WC and hypertension in women.

As shown in table 3, in both sexes, BMI adjusted for WC (residuals) appeared more strongly associated with hypertension while WC adjusted for BMI (residuals) was more evidently related with T2DM. Comparing with the lowest quartile of BMI residuals, the risk of hypertension increased 85% (95%CI: 1.59-2.15) in men and 1.23-fold (95%CI: 1.94-2.57) in women, whereas the risk of T2DM did not increase significantly in both sexes. On the other hand, the ORs of the highest versus the lowest quartile WC residuals for T2DM were 1.75 (95%CI: 1.33-2.30) in men and 2.37 (95%CI: 1.78-3.15) in women, higher than the OR of 1.57 (95%CI: 1.35-1.82) in men and 1.13 (95%CI: 0.98-1.30) in women for hypertension.

We further evaluated the potential joint effect of BMI and WC on T2DM and hypertension (table 4). The participants were classified into normal weight (BMI 18.5-23.9 kg/m^2), overweight (24.0-27.9 kg/m^2), or obese (≥ 28 kg/m^2) based on data from Chinese adults, and were defined as with normal or increased WC using sex-specific cut-offs (85 cm in men and 80 cm in women) [19]. The risk of T2DM and hypertension increased across groups defined by BMI and WC, with the highest risk observed among men with the lowest BMI but a higher WC, and among those with the highest BMI and a higher WC for hypertension. However, no significant interaction was observed between BMI and WC (all *P* values for interaction tests > 0.05).

Discussion

In this representative sample of the adult population in Shanghai, the largest city in China, we observed an increased prevalence of central obesity, hypertension and T2DM over the decade spanning 2002-2009. In contrast, BMI did not change over the same period. Our results present a snapshot of overt versus central obesity in the Chinese population and suggest that the epidemic of central obesity in this population, which has been more closely associated with the prevalence of T2DM, may lead to a more rapidly growing burden of T2DM in China.

Chinese adults have lower rates of overweight and obesity than their Western counterparts using the WHO criteria (BMI ≥ 25 kg/m^2 for overweight and BMI ≥ 30 kg/m^2 for obesity) [15 16].

Nevertheless, increasing trends of BMI in Chinese adults have been well documented [18 20]. In two national nutritional surveys undertaken in 1982 and 1992 in China, the prevalence of overweight/obesity (BMI $\geq$ 25 kg/m^2) in subjects 20-70 years of age was 10% and 15%, respectively. Between 1992 and 2002, the combined prevalence of overweight and obesity increased from 14.6 to 21.8% [21]. Interestingly, the increase in BMI among Chinese adults has slowed down during past decades [2]. In this study, we did not observe an increase in BMI and prevalence of obesity defined by the Chinese obesity standards or by WHO criteria (data not shown). Instead, we observed a significant increase in WC, a measure of central obesity between surveys. Our observation of increased WC in Chinese adults, without a concomitant increase in BMI, represents an increasing burden of central obesity in this population. The increase in central obesity indicates an upward trend in body fat percentages in the population who have been previously observed with higher body fat percentages compared to other ethnic people with the same BMI [22 23].

Both epidemic of overall and central obesity parallels a continuously increasing prevalence of hypertension and T2DM in China [21]. Several studies indicate that overall obesity (BMI) is more strongly associated with hypertension, while central obesity (WC) is more strongly associated with T2DM [17 24-26]. The rationale for these associations is based on the notion that central obesity reflects specific accumulation of visceral adipose tissue. Excess visceral adipose tissue is metabolically unfavorable due to productions of free fatty acids and inflammatory mediators. Overall obesity, on the other hand, represents a greater overall physiologic strain and effects vascular and cardiac parameters more significantly. In this study, we observed a significant increase in prevalence of T2DM regardless of gender or age groups, which was more pronounced than the change in the prevalence of hypertension during the period of 2002-03 and 2009. We also observed a closer association of central obesity with the prevalence of T2DM than with the prevalence of hypertension. These results support the notion that central obesity in particular is a stronger risk factor for T2DM than for hypertension in Chinese adults. Due to the cross-sectional design, however, our study was unable to make a causal inference.

The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM. The differences in several demographic characteristics between the participants of the two surveys indicate the changes in general population over time. However, selection bias could not be excluded. However, there are several strengths, including the strict process of multistage sampling in adult population in Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.

Conclusions

In summary, this study describes the potential association of central obesity with an upward trend of T2DM, implicating a more rapidly growing burden of T2DM than hypertension in Chinese adults. The findings in Shanghai, the largest city and one of the most economically developed areas in China, provide useful information for the projection of future trends in the whole country.

Acknowledgements

We thank Dr. Xiao-ou Shu and Dr. Hui Cai of Vanderbilt University for their contributions in study design and data analysis. The authors thank the study participants of the two cross-sectional surveys and the healthcare workers in each community involved.

Footnotes

Contributors YR and MM contributed to data collection, data analysis and draft of the paper. YR, YYL, QDY, and LS contributed to data collection and quality control. LJM contributed to revision of the paper. HZ contributed to data clean and analysis. RL and WHX contributed to study design, statistical analysis and revision of the paper. All authors contributed to the interpretation of data and revision of the manuscript. All authors approved the final version.

Funding This study was supported by the Key Program of Shanghai Municipal Committee of Science and Technology (04 DZ19502), the Shanghai Medical Development Program (01ZD001) and the Shanghai Municipal Health Bureau (GWDTR201204). W. H. Xu was supported by a training grant from the Fogarty International Center (D43 TW008313 to X. O. Shu). The funders had no role in study design, data collection or analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest: None declared.

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Figure 1. Shift in BMI and WC over the period of the two population-based surveys

Figure 2. Non-linear dose-response relationship of BMI and WC with hypertension and T2DM among participants of the two population-based surveys

363 Table 1. Characteristics of participants in two population-based surveys in Shanghai, China

Characteristics	1st survey Men (N=5,050)	1st survey Women (N=7,279)	2nd survey Men (N=3,461)	2nd survey Women (N=3,962)	*P-value between surveys* [a] *In men*	*P-value between surveys* [a] *In women*
Age (yrs., mean ± SD)	54.8 ± 10.8	53.1 ± 10.3	54.7 ± 9.5	54.7 ± 9.1	0.55	<0.0001
Resident site (%)						
Urban	71.1	63.0	72.4	72.0		
Rural	29.0	37.0	27.7	28.0	*0.19*	*<0.0001*
Education (%)						
No formal education	4.1	18.4	3.2	9.5		
Primary school	18.2	23.0	14.7	17.7		
Middle school	35.3	31.1	45.7	45.2		
High school	27.6	22.6	27.6	23.8		
Colleague or above	14.8	4.9	8.8	3.9	*0.0025*	*<0.0001*
Per capita income (yuan/mo.) (%)						
<1000	37.0	45.5	4.9	4.0		
1000-2999	38.3	38.4	41.8	46.7		
3000-5000	22.5	17.9	33.2	33.3		
>5000	2.2	1.3	20.0	16.0	*<0.0001*	*<0.0001*
Family history of type 2diabetes	12.3	13.1	16.4	19.0	*<0.0001*	*<0.0001*
Prevalence of type 2diabetes (%)	13.6	10.3	17.4	14.1	*<0.0001*	*<0.0001*
Prevalence of hypertension (%)	34.8	28.3	41.8	37.1	*<0.0001*	*<0.0001*
Cigarette smoking (%)	61.4	1.7	62.6	1.8	*0.22*	*0.93*
Alcohol drinking (%)	40.4	2.4	54.0	5.0	*<0.0001*	*<0.0001*
Leisure-time activity (%)	13.3	13.1	10.8	9.0	*0.0009*	*<0.0001*

364 [a] *P* for Wilcoxon tests or chi-square tests

Table 2. Prevalence of obesity, hypertension and type 2 diabetes in participants of the two population-based surveys by age groups in Shanghai, China

	No. of subjects		Overall Obesity		APC	Central obesity		APC	Hypertension		APC	Type 2 diabetes		APC
	1st survey	2nd survey	1st survey	2nd survey	(%)	1st survey	2nd survey	(%)	1st survey	2nd survey	(%)	1st survey	2nd survey	(%)
Men														
Overall	5050	3461	11.7	11.9	0.21	46.3	53.8	2.35	34.8	41.8	2.87	13.6	17.4	3.78
Age-groups														
35-	414	230	10.5	9.1	-2.11	41.8	45.2	1.22	15.2	11.7	-3.92	4.6	5.7	3.25
40-	574	302	10.0	8.3	-2.83	41.8	47.00	1.85	22.5	21.9	-0.43	7.8	7.6	-0.44
45-	837	445	12.6	12.6	-0.04	44.0	53.7	3.12	25.3	31.0	3.16	7.8	13.7	9.13
50-	833	739	12.2	10.8	-1.76	44.1	53.8	3.12	33.1	40.3	3.07	12.7	18.3	5.72
55-	628	669	10.4	13.2	3.78	47.3	54.6	2.25	35.4	45.6	3.99	15.0	17.9	2.82
60-	507	513	10.5	15.4	6.18	48.7	56.1	2.19	44.6	51.7	2.29	15.6	20.1	3.98
65-	674	313	12.6	11.8	-0.99	51.4	61.0	2.67	49.4	59.4	2.88	20.8	26.2	3.64
70-	583	250	13.8	9.6	-5.40	51.1	54.0	0.85	50.9	65.2	3.87	24.2	25.6	0.88
Women														
Overall	7279	3962	13.8	13.8	0.02	41.7	54.2	4.10	28.3	37.1	4.28	10.3	14.1	4.84
Age-groups														
35-	615	251	7.5	7.2	-0.65	22.6	26.3	2.35	6.8	10.8	7.24	3.3	4.0	3.17
40-	1000	287	9.4	11.2	2.66	27.6	38.0	5.05	11.7	15.7	4.61	4.1	5.9	5.81
45-	1491	563	11.0	9.8	-1.82	32.3	42.6	4.38	19.3	23.5	3.03	5.8	8.7	6.32
50-	1309	866	15.1	14.1	-1.00	43.9	54.0	3.24	28.7	31.0	1.16	8.3	9.4	1.94
55-	838	818	15.7	13.6	-2.17	47.5	60.6	3.83	33.9	39.7	2.48	8.8	15.3	8.80
60-	610	585	19.2	18.1	-0.87	53.5	63.1	2.58	40.5	52.8	4.17	16.7	19.2	2.11
65-	799	327	18.0	18.4	0.28	59.0	66.1	1.76	48.4	59.3	3.17	23.7	27.8	2.54
70-	617	265	18.2	16.6	-1.36	60.2	68.7	2.05	51.4	64.5	3.57	21.4	27.2	3.75
All subjects														
Overall	12329	7423	13.0	12.9	-0.05	43.6	54.0	3.35	31.0	39.3	3.75	11.7	15.6	4.53
Age-groups [a]														
35-	1029	481	8.7	8.0	-1.04	30.3	33.9	2.39	10.2	11.2	1.49	3.8	4.7	3.63
40-	1574	589	9.6	10.1	0.11	32.7	41.3	4.14	15.6	17.9	2.92	5.5	6.5	3.41
45-	2328	1008	11.6	10.8	-0.77	36.5	46.6	4.16	21.5	26.2	3.46	6.5	10.5	8.22
50-	2142	1605	13.9	12.8	-1.53	44.0	53.9	3.19	30.4	34.6	0.90	10.0	12.8	4.69
55-	1466	1487	13.4	13.4	0.01	47.4	58.1	3.13	34.5	42.2	3.20	11.5	16.4	5.75
60-	1117	1098	15.2	16.9	1.59	51.3	59.9	2.39	42.4	52.3	3.29	16.2	19.6	2.96
65-	1473	640	15.6	15.4	-0.39	55.5	63.8	2.11	48.9	59.4	3.04	22.3	27.1	2.98
70-	1200	515	16.0	13.2	-2.94	55.8	61.5	1.52	51.2	64.9	3.71	22.8	26.4	2.32

[a] adjusted for sex according to the distribution in the first survey.

Table 3. Association of body size with hypertension and type 2 diabetes in two population-based surveys in Shanghai, China

	No. of subjects with neither diseases	Type 2 diabetes only		Hypertension only		Both	
		N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
BMI residuals							
Men							
Q1	1260	156	1.00	529	1.00	175	1.00
Q2	1224	142	0.99 (0.77, 1.27)	583	1.16 (1.00, 1.34)	172	1.11(0.87, 1.41)
Q3	1164	132	1.09 (0.84, 1.41)	651	1.50 (1.29, 1.74)	171	1.36(1.07, 1.73)
Q4	1079	123	1.16 (0.88, 1.51)	709	1.85 (1.59, 2.15)	207	1.95(1.54, 2.47)
	P for trend		*0.2472*		*<0.0001*		*<0.0001*
Women							
Q1	1816	166	1.00	600	1.00	223	1.00
Q2	1866	148	1.02 (0.80, 1.29)	629	1.29 (1.12, 1.48)	162	0.96(0.77, 1.21)
Q3	1835	125	0.89 (0.69, 1.15)	687	1.51 (1.31, 1.73)	158	1.03(0.82, 1.31)
Q4	1634	109	0.94 (0.73, 1.23)	847	2.23 (1.94, 2.57)	215	1.85(1.15, 2.98)
	P for trend		*0.4864*		*<0.0001*		*0.0067*
All subjects							
Q1	3048	330	1.00	1162	1.00	385	1.00
Q2	3079	282	1.00 (0.84, 1.19)	1200	1.22 (1.11, 1.35)	363	1.03(0.87, 1.22)
Q3	2998	278	0.98 (0.82, 1.18)	1346	1.50 (1.36, 1.67)	302	1.18(1.00, 1.40)
Q4	2753	211	1.04 (0.86, 1.26)	1527	2.05 (1.85, 2.27)	433	1.88(1.60, 2.21)
	P for trend		0.2280		*<0.0001*		*<0.0001*
WC residuals							
Men							
Q1	1376	102	1.00	531	1.00	111	1.00
Q2	1232	131	1.34 (1.02, 1.78)	601	1.23 (1.06, 1.42)	155	1.41(1.07, 1.84)
Q3	1130	148	1.39 (0.70, 2.77)	644	1.39 (1.20, 1.62)	197	1.73(1.33, 2.25)
Q4	989	172	1.75 (1.33, 2.30)	696	1.57 (1.35, 1.82)	262	2.25(1.74, 2.90)
	P for trend		*<0.0001*		*<0.0001*		*<0.0001*
Women							
Q1	2019	80	1.00	598	1.00	108	1.00
Q2	1935	102	1.17 (0.86, 1.59)	651	1.04 (0.91, 1.18)	117	0.94(0.71, 1.25)
Q3	1708	172	2.04 (1.54, 2.70)	732	1.14 (0.99, 1.30)	194	1.40(1.08,1.82)
Q4	1489	194	2.37 (1.78, 3.15)	782	1.13 (0.98, 1.30)	339	2.06(1.26, 3.38)
	P for trend		*<0.0001*		*0.0216*		*<0.0001*
All subjects							
Q1	3453	161	1.00	1109	1.00	203	1.00
Q2	3192	260	1.26 (0.99, 1.60)	1211	1.12 (1.01, 1.23)	260	1.16(0.82, 1.62)
Q3	2838	301	1.66 (1.16, 2.36)	1373	1.25 (1.13, 1.38)	412	1.55(1.29, 1.87)
Q4	2395	379	2.03 (1.66, 2.47)	1542	1.34 (1.09, 1.64)	608	2.18(1.83, 2.61)
	P for trend		*0.0001*		*0.0021*		*<0.0001*

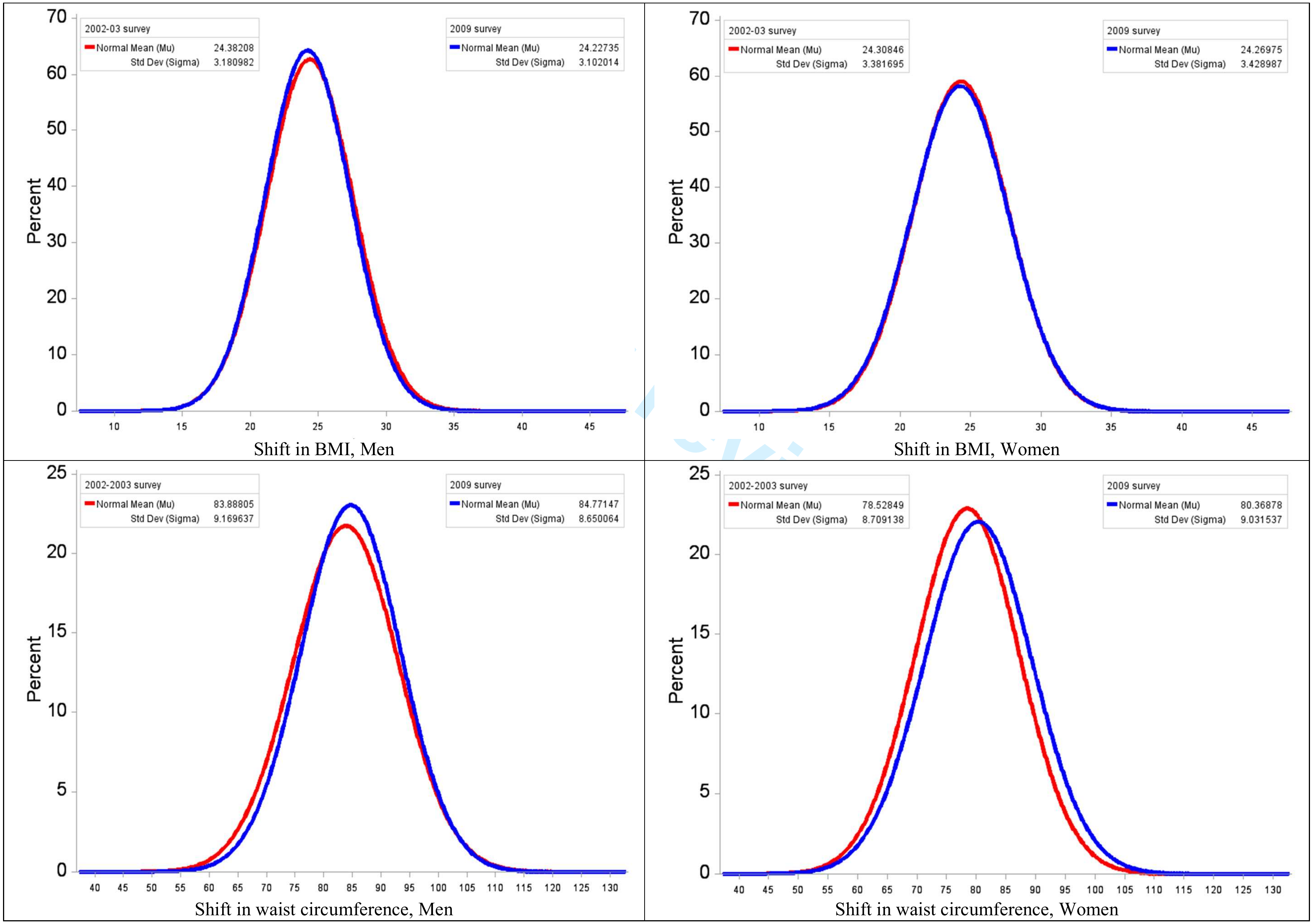
Missing value excluded from the analysis.
OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), phase of study (first /second survey); Additionally adjusted for sex (male/female) for all subjects.

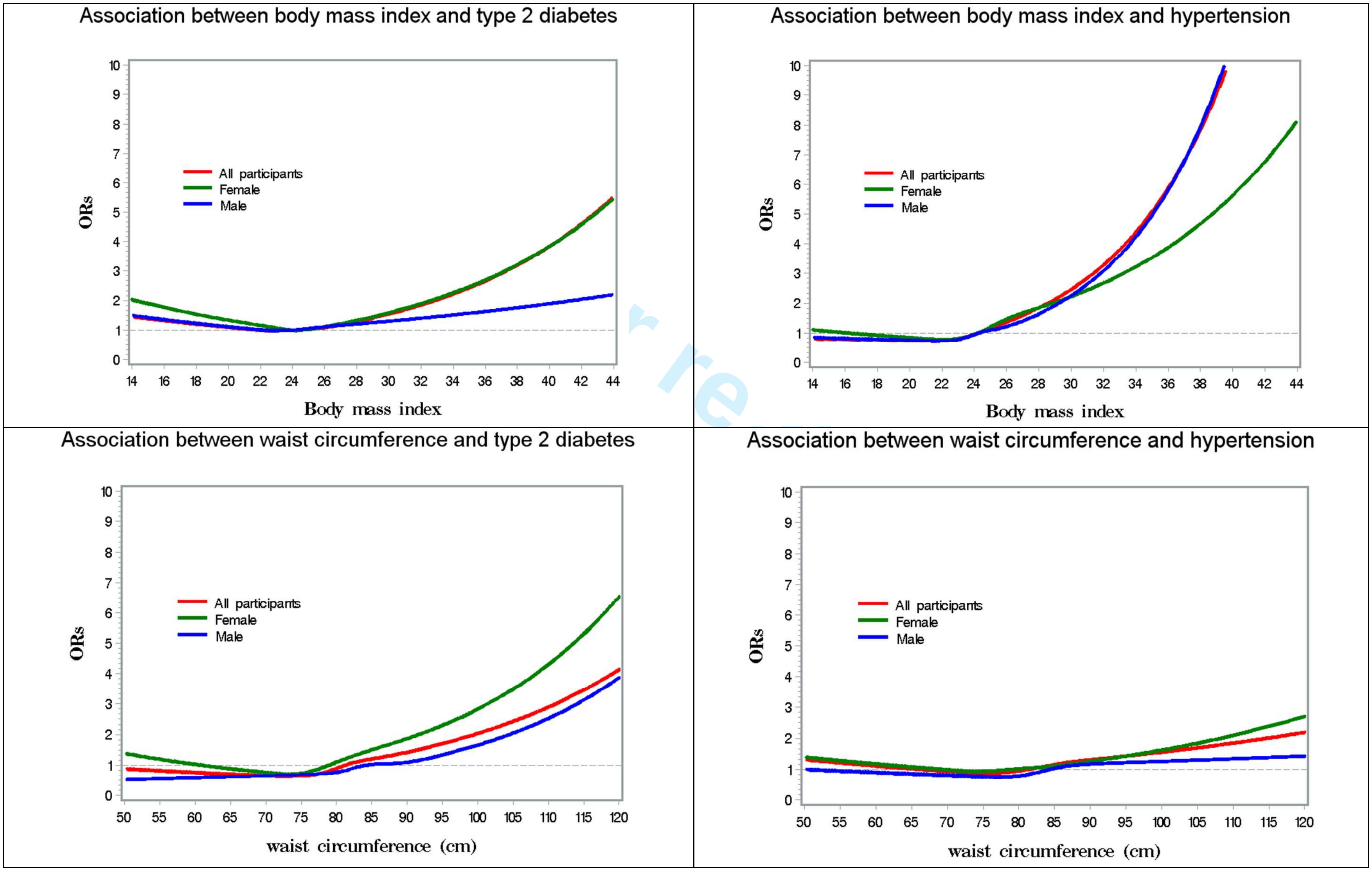
Table 4. Joint effect of general obesity and central obesity on type 2 diabetes among Chinese adults

BMI	WC：Lower			WC: Higher			OR (95%CI) for hypertension		OR (95%CI) for type 2 diabetes	
	No. of subjects	Hypertension N (%)	Diabetes N (%)	No. of subjects	Hypertension N (%)	Diabetes N (%)	WC: Lower	WC: Higher	WC: Lower	WC: Higher
Men										
<18.5	212	36	20	16	10	6	0.61(0.42, 0.89)	3.68(1.28, 10.59)	1.02(0.62, 1.67)	3.77(1.13, 12.56)
18.5-23.9	3034	767	296	679	249	111	1.00	1.56(0.94, 2.57)	1.00	1.48(1.15, 1.90)
24.0-27.9	1010	356	134	2530	1179	483	1.61(1.13, 2.32)	2.38(1.78, 3.17)	1.46(1.16, 1.83)	1.85(1.16, 2.96)
⩾28.0	36	20	4	960	580	224	3.91(1.95, 7.82)	4.67(3.97, 5.49)	1.71(0.55, 5.37)	2.60(2.12, 3.18)
						P for interaction	*0.0711*		*0.0933*	
Women										
<18.5	313	51	19	8	2	1	0.68(0.49, 0.94)	0.85(0.16, 4.51)	0.93(0.56, 1.54)	2.45(0.22, 26.72)
18.5-23.9	4323	821	265	974	314	165	1.00	1.48(1.26, 1.75)	1.00	2.36(1.89, 2.94)
24.0-27.9	1330	384	93	2724	1102	437	1.84(1.59, 2.14)	2.21(1.97, 2.49)	1.19(0.92, 1.53)	2.14(1.81, 2.54)
≥28.0	81	32	9	1467	815	317	3.10(1.93, 5.00)	4.33(3.77, 4.96)	2.14(1.01, 4.52)	3.08(2.56, 3.71)
						P for interaction	*0.3524*		*0.4011*	
Total										
<18.5	525	87	39	24	12	7	0.65(0.51, 0.83)	2.25(0.85, 5.93)	0.97(0.68, 1.39)	3.45(1.18, 10.12)
18.5-23.9	7357	1588	561	1653	563	276	1.00	1.52(1.25, 1.85)	1.00	1.88(1.42, 2.49)
24.0-27.9	2340	740	227	5254	2281	920	1.74(1.50, 2.03)	2.31(2.03, 2.62)	1.33(1.12, 1.58)	1.99(1.62, 2.45)
⩾28.0	117	5	13	2427	1395	541	3.34(2.26, 4.94)	4.46(4.02, 4.96)	2.00(1.07, 3.74)	2.85(2.49, 3.27)
						P for interaction	*0.0562*		*0.0798*	

Higher WC defined as ≥ 85 cm for men and ≥ 80 cm for women

OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), and phase of study (first /second survey).


2002-03 survey
Normal Mean (Mu) 24.38208
Std Dev (Sigma) 3.180982
2009 survey
Normal Mean (Mu) 24.22735
Std Dev (Sigma) 3.102014
Percent
Shift in BMI, Men
2002-03 survey
Normal Mean (Mu) 24.30846
Std Dev (Sigma) 3.381695
2009 survey
Normal Mean (Mu) 24.26975
Std Dev (Sigma) 3.428987
Percent
Shift in BMI, Women
2002-2003 survey
Normal Mean (Mu) 83.88805
Std Dev (Sigma) 9.169637
2009 survey
Normal Mean (Mu) 84.77147
Std Dev (Sigma) 8.650064
Percent
Shift in waist circumference, Men
2002-2003 survey
Normal Mean (Mu) 78.52849
Std Dev (Sigma) 8.709138
2009 survey
Normal Mean (Mu) 80.36878
Std Dev (Sigma) 9.031537
Percent
Shift in waist circumference, Women


Association between body mass index and type 2 diabetes
All participants
Female
Male
ORs
Body mass index
Association between body mass index and hypertension
All participants
Female
Male
ORs
Body mass index
Association between waist circumference and type 2 diabetes
All participants
Female
Male
ORs
waist circumference (cm)
Association between waist circumference and hypertension
All participants
Female
Male
ORs
waist circumference (cm)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Results of check
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	We have indicated that the study was based on two population-based cross-sectional surveys in the title and the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Line 53-62
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Line 72-87
Objectives	3	State specific objectives, including any prespecified hypotheses	Line 89-92
Methods			
Study design	4	Present key elements of study design early in the paper	Line 95-104
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Line 95-104
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Line 95-104
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Line 117-153
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Line 117-153
Bias	9	Describe any efforts to address potential sources of bias	Line 117-153
Study size	10	Explain how the study size was arrived at	NA
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Line 155-169
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Line 155-169
		(*b*) Describe any methods used to	Line 166-167

		examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	There were very few missing data in this study. Please see footnote of the Table 3
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	No
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Line 95-105
		(b) Give reasons for non-participation at each stage	No information
		(c) Consider use of a flow diagram	No
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Line 172-177, and Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Yes, we provide number of subjects for each variable of interest (Please see tables)
Outcome data	15*	Report numbers of outcome events or summary measures	Yes (Please see tables)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	No. Due to the large table, we present only adjusted ORs
		(*b*) Report category boundaries when continuous variables were categorized	Yes (Please see table 4)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Line 210-217
Discussion			
Key results	18	Summarise key results with reference to study objectives	Line 219-224
Limitations	19	Discuss limitations of the study, taking into account sources of	Line 253-259

		potential bias or imprecision. Discuss both direction and magnitude of any potential bias	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Line 251-252
Generalisability	21	Discuss the generalisability (external validity) of the study results	Line 263-264
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Line 275-280

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2013-003408.R2
Article Type:	Research
Date Submitted by the Author:	03-Sep-2013
Complete List of Authors:	Ruan, Ye; Shanghai Municipal Center for Disease Control and Prevention, Department of Diabetes Prevention and Control Mo, Miao; School of Public Health, Fudan University, Department of Epidemiology Joss-Moore, Lisa; University of Utah, Division of Neonatology Li, Yan Yun; Shanghai Municipal Center for Disease Control and Prevention, Department of Diabetes Prevention and Control Yang, Qun Di; Shanghai Municipal Center for Disease Control and Prevention, Department of Diabetes Prevention and Control Shi, Liang; Shanghai Municipal Center for Disease Control and Prevention, Department of Diabetes Prevention and Control Zhang, Hua; School of Public Health, Fudan University, Department of Epidemiology Li, Rui; Shanghai Municipal Center for Disease Control and Prevention, Department of Diabetes Prevention and Control Xu, Wang Hong; Fudan University, Department of Epidemiology, School of Public Health
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Epidemiology, Public health, Cardiovascular medicine, Diabetes and endocrinology
Keywords:	Hypertension < CARDIOLOGY, General diabetes < DIABETES & ENDOCRINOLOGY, EPIDEMIOLOGY, PUBLIC HEALTH

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Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

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RUNNING HEADER: Obesity and prevalence of hypertension and T2DM in Chinese adults

Word Count:

Abstract: 249

Text: 2,658

Abstract:

Objective: To evaluate the changes in body mass index (BMI) and waist circumference (WC) and their associations with the prevalence of hypertension and type 2 diabetes (T2DM) in Chinese adults.

Design: Two consecutive population-based cross-sectional surveys.

Setting: A total of 12 districts and 7 counties in Shanghai, China.

Participants: 12,329 randomly selected participants of the survey in 2002-2003, and 7,423 randomly selected participants of the survey in 2009. All subjects were residents of Shanghai aged 35-74 years old.

Outcome measures: Measured BMI and WC. Previously-diagnosed and newly-identified hypertension and T2DM by measured blood pressure, fasting and post-load glucose.

Results: While the participants of the two surveys were comparable in BMI in each age group, the participants of the 2009 survey had significantly larger WC than those of the 2002-03 survey, with an annual percentage change (APC) being higher among subjects aged 45-49 years old in both men and women. The increase in prevalence of T2DM was observed in all age groups and also appeared more evident in subjects aged 45-49 years old. The prevalence of hypertension was observed to increase more rapidly in elderly men and middle-aged women. Obesity, both overt and central, was associated with the risk of the two diseases, but BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM.

Conclusion: The prevalence of central obesity and related chronic diseases has been increasing in Shanghai, China. Our findings provide useful information for the projection of growing burden of T2DM and hypertension in Chinese adults.

Keywords: type 2 diabetes; hypertension; prevalence; body mass index; waist circumference

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Article summary

Article focus

- The shift in BMI and WC among Chinese adults over past one decade.
- The contribution of changes in overall and central obesity to the increasing burden of chronic disease in China.

Key messages

- The WC increased in Chinese adults over the decade spanning 2002-2009, while BMI did not change over the same period.
- BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM in Chinese adults.
- Our findings provide useful information for the projection of a growing burden of T2DM and hypertension in Chinese adults.

Strengths and limitations of this study

- The strengths of this study include the strict process of multistage sampling in adult population of Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.
- The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM.
- The differences in several demographic characteristics between the participants of the two surveys indicate the possibility of selection bias.

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Introduction

A rising worldwide prevalence of chronic disease, manifested primarily as hypertension and type 2 diabetes (T2DM), has been well documented [1-4]. In Chinese aged 15-74 years old, the prevalence of hypertension increased from 5.11% in 1959, 7.73% in 1979 [5] and 13.58% in 1991[6] to 17.65% in 2002 [7]. The prevalence of T2DM tripled between 1980 (about 1.0%) and 1996 (3.2%) [8 9], and reached 9.7% in 2008 among adults at 20 years old or above [10]. It is estimated that over 92 million people in China have T2DM. This represents approximately half of the world's diabetic population, and places China at the "global epicenter of the diabetes epidemic" [4].

Both hypertension and T2DM are associated with obesity [11 12]. Obesity is often measured by body mass index (BMI). Across the entire range of BMI, the risk of hypertension and T2DM increases, making a higher BMI a strong predictor of both hypertension and T2DM [4 12-14]. However, a significant proportion of Asian adults diagnosed with T2DM are with the normal BMI, ie.18.5-25.0 kg/m^2 [15 16]. BMI is a general indicator of overt obesity, but does not give information about the distribution of obesity. Central obesity, often assessed via waist circumference (WC), is also strongly correlated with T2DM in both European and Asian adults [11 17]. While changes in BMI have been well documented in China over past several decades [2 18], changes in WC, and thus central obesity, are not well described.

In this study, we took advantage of the data from population based cross-sectional surveys conducted in Shanghai in 2002-03 and in 2009. We used the data from the two surveys to evaluate correlations between shifts in BMI and WC with the prevalence of hypertension and T2DM in Chinese adults. Our results may help to better understand the contribution of overall obesity and central obesity in the increasing burden of chronic disease in China.

Materials and Methods

Study Participants

A representative sample of the general population was randomly selected through a multistage sampling process in the 2002-03 survey. Firstly, 4 districts and 2 counties were randomly selected

from a total of 12 districts and 7 counties in Shanghai, China. And then, 1-2 sub-districts or towns were randomly selected from each selected district or county. Next, 1-2 communities or villages, usually 1,000-2,000 residents for each, were randomly selected from each selected sub-district or town. Finally, eligible subjects (permanent residents of Shanghai, 15-74 years old and having been in the city for at least 5 years) were randomly selected from the selected communities and villages and were invited for participation. Pregnant women, individuals with type I diabetes, and physically or mentally disabled persons were excluded from the participation. During the period of May 2002-October 2003, a total of 17,526 eligible subjects were recruited, and 14,401 (82.17%) participated the survey.

The 2009 survey used the similar sampling method except that only 7 communities and villages were randomly selected in the third stage of sampling. The inclusion and exclusion criteria of the 2009 survey were also similar to those for the 2002-03 survey, except that only those at the age of 35-74 years old were eligible for the 2009 survey. Among 7,627 eligible adults contacted during the period of May-July 2009, 7,414 (97.21%) were interviewed and donated blood samples.

To make the two surveys comparable, we excluded 1,071 subjects younger than 35 years from the 2002-03 survey. After further excluding subjects with missing information, the final analysis included 5,050 men and 7,279 women in the 2002-03 survey and 3,461 men and 3,962 women in the 2009 survey. The Institutional Review Board at Shanghai Municipal Center of Disease Control and Prevention approved the study. Informed consent was obtained from each participant before data collection and laboratory measurements.

Data Collection

A similar survey approach was followed by the two investigations. In both surveys, information on demographic and socioeconomic factors, diagnosis of diabetes, tobacco and alcohol use, physical activity and family history of diabetes was collected by trained interviewers with a structured questionnaire at community clinics located in the residential areas of the participants.

At the interview, each participant's blood pressure, body weight, standing height, and waist

circumference (WC) were measured by trained staff. Blood pressure was measured on the right arm in the sitting position using standard mercury sphygmomanometer after at least 5 minutes of rest. The first and fifth Korotkoff sounds were recorded. Body weight and height were recorded while the subject was in light clothing and without shoes. Body weight was measured with electronic scales to the nearest 0.1 kg. Body height was measured to the nearest 0.1 cm by using a stadiometer. WC, recorded to the nearest 0.1 cm, was taken with a cloth tape and was measured on bare skin at the midline between the lower border of the ribs and the iliac crest in the horizontal plane after a normal expiration. Two measurements were taken and the mean of the replicates was used in the following analyses. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2) using the direct measurements.

Laboratory Measurements

After at least 10 hours of overnight fasting, 1-1.5 ml venous blood specimen was collected in a vacuum tube containing sodium fluoride. All participants with no history of diabetes and having a fasting plasma glucose level of < 7.0 mmol per liter (mmol/l) were then asked to have an oral glucose-tolerance test (OGTT). Blood samples were drawn at 0 and 120 minutes after a standard 75 gram glucose load. Plasma glucose was measured with Glucose oxidase-peroxidase (GOD-PAP) method.

Diagnosis of T2DM and Hypertension

Previously diagnosed T2DM and hypertension was identified by a positive response from the participant to the question of "Have you ever diagnosed with T2DM/hypertension by a doctor?" and confirmed by medical records in which prescriptions of anti-hypertensive or hypoglycemic medications were presented. The consistent rate was 100%. For those who had a negative response, the T2DM was diagnosed with measured glucose level by using the 1999 World Health Organization diagnostic criteria [Department of Noncommunicable Disease Surveillance. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1. Diagnosis and classification of diabetes mellitus. Geneva: World Health

Organization, 1999. (Accessed July 5, 2010, at http://www.staff.ncl.ac.uk/philip.home/who_dmg.pdf.)] and hypertension referred to the subjects with measured systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg and confirmed by clinical visits. Total T2DM and hypertension included both previously diagnosed and newly-diagnosed patients. 42.7% (1,110 of 2,598) diabetic patients and 10.3% (694 of 6,735) hypertensive patients were newly-diagnosed in the two surveys.

Statistical Analysis

SAS software 9.2 was used for all the statistical analyses. Characteristics of the subgroups were described using summary statistics (median, 25^{th} and 75^{th} percentile, frequencies, and percentages) separately for men and women. The differences between two surveys were compared using χ^2 test (category variables) and Wilcoxon tests (continuous variables). The annual percentage changes (APC) in prevalence between two surveys were calculated as (prevalence in 2009 – prevalence in 2002-03) / number of years using logarithms for each age group. Percentile curves were constructed for BMI and WC values in the two surveys by gender using the LMS (lambda, mu, sigma) method. Restricted cubic splines (RCS) were used to model a potential curvilinear relationship of BMI and WC with hypertension and diabetes using the 5^{th}, 25^{th}, 75^{th} and 95^{th} percentiles as fixed knots and the 50^{th} percentile as the reference. Polynomial logistic regression were used to estimate the odds ratios (OR) and 95% confidence intervals (95% CI) of BMI and WC with T2DM and hypertension. Meta-analysis was applied to obtain the combined ORs and 95% CI considering the potential heterogeneity of the populations in the two surveys. The residual method was used to derive the independent effect of BMI and WC with each other in the models. *P* value less than 0.05 was considered as a test of significance based on two sides.

Results

The male participants in two studies were similar in age, resident site and cigarette smoking while the female participants were comparable in cigarette smoking ($P > 0.05$) (Table 1). Compared to the subjects in 2002-03 survey, the participants of 2009 survey, both men and women, had lower level of education, higher level of income per capita, more prior history of T2DM, higher frequency of alcohol drinking and lower frequency of leisure time activity, and were more likely to have a family history of diabetes.

Figure 1 shows the shapes of the BMI and WC distribution curves among men and women changed over the period of the two surveys. After adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, and family history of T2DM, the curves of BMI were almost overlapped in both men and women. However, the WC curves for men and women were shifted to the right between 2002-03 and 2009, with the mean WC increasing from 83.6 to 85.3 cm for men and from 78.4 to 80.6 cm for women.

As presented in table 2, the prevalence of obesity, both overall and central, increased with increasing age groups. While the prevalence of overall obesity (BMI $\geq$ 28 kg/m^2) did not change between two surveys (all P values > 0.05), the prevalence of central obesity was significantly higher in 2009 survey in each age group (all P values < 0.001). A more pronounced increase in the prevalence of central obesity and T2DM was observed among subjects aged 45-49 years old in both men and women; whereas the change in the prevalence of hypertension between two surveys appeared more evident in older men and younger women over the period. Using the World Health Organization (WHO) criteria for obesity did not change the results substantially (data not shown in the tables).

BMI and WC were highly correlated with each other, with a correlation coefficient of 0.77 (P < 0.0001) among men and 0.78 (P < 0.0001) among women after adjusting for age. Therefore, the residual method was used to test the potential respective non-linear relationships of BMI and WC with the risk of T2DM and hypertension (Figure 2). The dose-response analysis likewise showed a statistically significant increased risk of T2DM at high level of WC and a significant elevated risk of hypertension at high level of BMI in both men and women after adjusting for age, education, per capita income, resident site, smoking, alcohol consumption, regular exercise, family history of T2DM and phase of surveys, with P values for non-linear relationship tests < 0.05. No significant relationship was observed between BMI and T2DM in men and between WC and hypertension in women.

As shown in table 3, in both sexes, BMI adjusted for WC (residuals) appeared more strongly associated with hypertension while WC adjusted for BMI (residuals) was more evidently related with T2DM. Comparing with the lowest quartile of BMI residuals, the risk of hypertension increased 85% (95%CI: 1.59-2.15) in men and 1.23-fold (95%CI: 1.94-2.57) in women, whereas the risk of T2DM did not increase significantly in both sexes. On the other hand, the ORs of the highest versus the lowest quartile WC residuals for T2DM were 1.75 (95%CI: 1.33-2.30) in men and 2.37 (95%CI: 1.78-3.15) in women, higher than the OR of 1.57 (95%CI: 1.35-1.82) in men and 1.13 (95%CI: 0.98-1.30) in women for hypertension.

We further evaluated the potential joint effect of BMI and WC on T2DM and hypertension (table 4). The participants were classified into normal weight (BMI 18.5-23.9 kg/m^2), overweight (24.0-27.9 kg/m^2), or obese (≥ 28 kg/m^2) based on data from Chinese adults, and were defined as with normal or increased WC using sex-specific cut-offs (85 cm in men and 80 cm in women) [19]. The risk of T2DM and hypertension increased across groups defined by BMI and WC, with the highest risk observed among men with the lowest BMI but a higher WC, and among those with the highest BMI and a higher WC for hypertension. However, no significant interaction was observed between BMI and WC (all *P* values for interaction tests > 0.05).

Discussion

In this representative sample of the adult population in Shanghai, the largest city in China, we observed an increased prevalence of central obesity, hypertension and T2DM over the decade spanning 2002-2009. In contrast, BMI did not change over the same period. Our results present a snapshot of overt versus central obesity in the Chinese population and suggest that the epidemic of central obesity in this population, which has been more closely associated with the prevalence of T2DM, may lead to a more rapidly growing burden of T2DM in China.

Chinese adults have lower rates of overweight and obesity than their Western counterparts using the WHO criteria (BMI ≥ 25 kg/m^2 for overweight and BMI ≥ 30 kg/m^2 for obesity) [15 16]. Nevertheless, increasing trends of BMI in Chinese adults have been well documented [18 20]. In two national nutritional surveys undertaken in 1982 and 1992 in China, the prevalence of overweight/obesity (BMI ≥ 25 kg/m^2) in subjects 20-70 years of age was 10% and 15%, respectively. Between 1992 and 2002, the combined prevalence of overweight and obesity increased from 14.6 to 21.8% [21]. Interestingly, the increase in BMI among Chinese adults has slowed down during past decades [2]. In this study, we did not observe an increase in BMI and prevalence of obesity defined by the Chinese obesity standards or by WHO criteria (data not shown). Instead, we observed a significant increase in WC, a measure of central obesity between surveys. Our observation of increased WC in Chinese adults, without a concomitant increase in BMI, represents an increasing burden of central obesity in this population. The increase in central obesity indicates an upward trend in body fat percentages in the population who have been previously observed with higher body fat percentages compared to other ethnic people with the same BMI [22 23].

Both epidemics of overall and central obesity parallel a continuously increasing prevalence of hypertension and T2DM in China [21]. Several studies indicate that overall obesity (BMI) is more strongly associated with hypertension, while central obesity (WC) is more strongly associated with T2DM [17 24-26]. The rationale for these associations is based on the notion that central obesity reflects specific accumulation of visceral adipose tissue. Excess visceral adipose tissue is metabolically unfavorable due to productions of free fatty acids and inflammatory mediators. Overall obesity, on the other hand, represents a greater overall physiologic strain and effects vascular and cardiac parameters more significantly. In this study, we observed a significant increase in prevalence of T2DM regardless of gender or age groups, which was more pronounced than the change in the prevalence of hypertension during the period of 2002-03 and 2009. We also observed a closer association of central obesity with the prevalence of T2DM than with the prevalence of hypertension. These results support the notion that central obesity in particular is a stronger risk factor for T2DM than for hypertension in Chinese adults. Due to the cross-sectional design, however, our study was unable to make a causal inference.

The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM. The differences in several demographic characteristics between the participants of the two surveys indicate the changes in general population over time. However, selection bias could not be excluded. There are several strengths in this study, including the strict process of multistage sampling in adult population in Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.

Conclusions

In summary, this study describes the potential association of central obesity with an upward trend of T2DM. Our findings provide useful information about the growing burden of type 2 diabetes and hypertension in Chinese adults and suggest the need for further study in other rapidly changing populations in China.

Acknowledgements

We thank Dr. Xiao-ou Shu and Dr. Hui Cai of Vanderbilt University for their contributions in study design and data analysis. The authors thank the study participants of the two cross-sectional surveys and the healthcare workers in each community involved.

Footnotes

Contributors YR and MM contributed to data collection, data analysis and draft of the paper. YR, YYL, QDY, and LS contributed to data collection and quality control. LJM contributed to revision of the paper. HZ contributed to data clean and analysis. RL and WHX contributed to study design, statistical analysis and revision of the paper. All authors contributed to the interpretation of data and revision of the manuscript. All authors approved the final version.

Funding This study was supported by the Key Program of Shanghai Municipal Committee of Science and Technology (04 DZ19502), the Shanghai Medical Development Program (01ZD001) and the Shanghai Municipal Health Bureau (GWDTR201204). W. H. Xu was supported by a training grant from the Fogarty International Center (D43 TW008313 to X. O. Shu). The funders had no role in study design, data collection or analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest: None declared.

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361 Figure 1. Shift in BMI and WC over the period of the two population-based surveys

362 Figure 2. Non-linear dose-response relationship of BMI and WC with hypertension and T2DM

363 among participants of the two population-based surveys

364

365 Table 1. Characteristics of participants in two population-based surveys in Shanghai, China

Characteristics	1st survey		2nd survey		*P-value between surveys* [a]	
	Men (N=5,050)	Women (N=7,279)	Men (N=3,461)	Women (N=3,962)	*In men*	*In women*
Age (yrs., mean ± SD)	54.8 ± 10.8	53.1 ± 10.3	54.7 ± 9.5	54.7 ± 9.1	0.55	<0.0001
Resident site (%)						
Urban	71.1	63.0	72.4	72.0		
Rural	29.0	37.0	27.7	28.0	*0.19*	*<0.0001*
Education (%)						
No formal education	4.1	18.4	3.2	9.5		
Primary school	18.2	23.0	14.7	17.7		
Middle school	35.3	31.1	45.7	45.2		
High school	27.6	22.6	27.6	23.8		
Colleague or above	14.8	4.9	8.8	3.9	*0.0025*	*<0.0001*
Per capita income (yuan/mo.) (%)						
<1000	37.0	45.5	4.9	4.0		
1000-2999	38.3	38.4	41.8	46.7		
3000-5000	22.5	17.9	33.2	33.3		
>5000	2.2	1.3	20.0	16.0	*<0.0001*	*<0.0001*
Family history of type 2diabetes	12.3	13.1	16.4	19.0	*<0.0001*	*<0.0001*
Prevalence of type 2diabetes (%)	13.6	10.3	17.4	14.1	*<0.0001*	*<0.0001*
Prevalence of hypertension (%)	34.8	28.3	41.8	37.1	*<0.0001*	*<0.0001*
Cigarette smoking (%)	61.4	1.7	62.6	1.8	*0.22*	*0.93*
Alcohol drinking (%)	40.4	2.4	54.0	5.0	*<0.0001*	*<0.0001*
Leisure-time activity (%)	13.3	13.1	10.8	9.0	*0.0009*	*<0.0001*

366 [a] *P* for Wilcoxon tests or chi-square tests

Table 2. Prevalence of obesity, hypertension and type 2 diabetes in participants of the two population-based surveys by age groups in Shanghai, China

	No. of subjects		Overall Obesity		*APC*	Central obesity		*APC*	Hypertension		*APC*	Type 2 diabetes		*APC*
	1st survey	2nd survey	1st survey	2nd survey	*(%)*	1st survey	2nd survey	*(%)*	1st survey	2nd survey	*(%)*	1st survey	2nd survey	*(%)*
Men														
Overall	5050	3461	11.7	11.9	*0.21*	46.3	53.8	*2.35*	34.8	41.8	*2.87*	13.6	17.4	*3.78*
Age-groups														
35-	414	230	10.5	9.1	*-2.11*	41.8	45.2	*1.22*	15.2	11.7	*-3.92*	4.6	5.7	*3.25*
40-	574	302	10.0	8.3	*-2.83*	41.8	47.00	*1.85*	22.5	21.9	*-0.43*	7.8	7.6	*-0.44*
45-	837	445	12.6	12.6	*-0.04*	44.0	53.7	*3.12*	25.3	31.0	*3.16*	7.8	13.7	*9.13*
50-	833	739	12.2	10.8	*-1.76*	44.1	53.8	*3.12*	33.1	40.3	*3.07*	12.7	18.3	*5.72*
55-	628	669	10.4	13.2	*3.78*	47.3	54.6	*2.25*	35.4	45.6	*3.99*	15.0	17.9	*2.82*
60-	507	513	10.5	15.4	*6.18*	48.7	56.1	*2.19*	44.6	51.7	*2.29*	15.6	20.1	*3.98*
65-	674	313	12.6	11.8	*-0.99*	51.4	61.0	*2.67*	49.4	59.4	*2.88*	20.8	26.2	*3.64*
70-	583	250	13.8	9.6	*-5.40*	51.1	54.0	*0.85*	50.9	65.2	*3.87*	24.2	25.6	*0.88*
Women														
Overall	7279	3962	13.8	13.8	*0.02*	41.7	54.2	*4.10*	28.3	37.1	*4.28*	10.3	14.1	*4.84*
Age-groups														
35-	615	251	7.5	7.2	*-0.65*	22.6	26.3	*2.35*	6.8	10.8	*7.24*	3.3	4.0	*3.17*
40-	1000	287	9.4	11.2	*2.66*	27.6	38.0	*5.05*	11.7	15.7	*4.61*	4.1	5.9	*5.81*
45-	1491	563	11.0	9.8	*-1.82*	32.3	42.6	*4.38*	19.3	23.5	*3.03*	5.8	8.7	*6.32*
50-	1309	866	15.1	14.1	*-1.00*	43.9	54.0	*3.24*	28.7	31.0	*1.16*	8.3	9.4	*1.94*
55-	838	818	15.7	13.6	*-2.17*	47.5	60.6	*3.83*	33.9	39.7	*2.48*	8.8	15.3	*8.80*
60-	610	585	19.2	18.1	*-0.87*	53.5	63.1	*2.58*	40.5	52.8	*4.17*	16.7	19.2	*2.11*
65-	799	327	18.0	18.4	*0.28*	59.0	66.1	*1.76*	48.4	59.3	*3.17*	23.7	27.8	*2.54*
70-	617	265	18.2	16.6	*-1.36*	60.2	68.7	*2.05*	51.4	64.5	*3.57*	21.4	27.2	*3.75*
All subjects														
Overall	12329	7423	13.0	12.9	*-0.05*	43.6	54.0	*3.35*	31.0	39.3	*3.75*	11.7	15.6	*4.53*
Age-groups [a]														
35-	1029	481	8.7	8.0	*-1.04*	30.3	33.9	*2.39*	10.2	11.2	*1.49*	3.8	4.7	*3.63*
40-	1574	589	9.6	10.1	*0.11*	32.7	41.3	*4.14*	15.6	17.9	*2.92*	5.5	6.5	*3.41*
45-	2328	1008	11.6	10.8	*-0.77*	36.5	46.6	*4.16*	21.5	26.2	*3.46*	6.5	10.5	*8.22*
50-	2142	1605	13.9	12.8	*-1.53*	44.0	53.9	*3.19*	30.4	34.6	*0.90*	10.0	12.8	*4.69*
55-	1466	1487	13.4	13.4	*0.01*	47.4	58.1	*3.13*	34.5	42.2	*3.20*	11.5	16.4	*5.75*
60-	1117	1098	15.2	16.9	*1.59*	51.3	59.9	*2.39*	42.4	52.3	*3.29*	16.2	19.6	*2.96*
65-	1473	640	15.6	15.4	*-0.39*	55.5	63.8	*2.11*	48.9	59.4	*3.04*	22.3	27.1	*2.98*
70-	1200	515	16.0	13.2	*-2.94*	55.8	61.5	*1.52*	51.2	64.9	*3.71*	22.8	26.4	*2.32*

[a] adjusted for sex according to the distribution in the first survey.

Table 3. Association of body size with hypertension and type 2 diabetes in two population-based surveys in Shanghai, China

	No. of subjects with neither diseases	Type 2 diabetes only		Hypertension only		Both	
		N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
BMI residuals							
Men							
Q1	1260	156	1.00	529	1.00	175	1.00
Q2	1224	142	0.99 (0.77, 1.27)	583	1.16 (1.00, 1.34)	172	1.11(0.87, 1.41)
Q3	1164	132	1.09 (0.84, 1.41)	651	1.50 (1.29, 1.74)	171	1.36(1.07, 1.73)
Q4	1079	123	1.16 (0.88, 1.51)	709	1.85 (1.59, 2.15)	207	1.95(1.54, 2.47)
	P for trend		*0.2472*		*<0.0001*		*<0.0001*
Women							
Q1	1816	166	1.00	600	1.00	223	1.00
Q2	1866	148	1.02 (0.80, 1.29)	629	1.29 (1.12, 1.48)	162	0.96(0.77, 1.21)
Q3	1835	125	0.89 (0.69, 1.15)	687	1.51 (1.31, 1.73)	158	1.03(0.82, 1.31)
Q4	1634	109	0.94 (0.73, 1.23)	847	2.23 (1.94, 2.57)	215	1.85(1.15, 2.98)
	P for trend		*0.4864*		*<0.0001*		*0.0067*
All subjects							
Q1	3048	330	1.00	1162	1.00	385	1.00
Q2	3079	282	1.00 (0.84, 1.19)	1200	1.22 (1.11, 1.35)	363	1.03(0.87, 1.22)
Q3	2998	278	0.98 (0.82, 1.18)	1346	1.50 (1.36, 1.67)	302	1.18(1.00, 1.40)
Q4	2753	211	1.04 (0.86, 1.26)	1527	2.05 (1.85, 2.27)	433	1.88(1.60, 2.21)
	P for trend		0.2280		*<0.0001*		*<0.0001*
WC residuals							
Men							
Q1	1376	102	1.00	531	1.00	111	1.00
Q2	1232	131	1.34 (1.02, 1.78)	601	1.23 (1.06, 1.42)	155	1.41(1.07, 1.84)
Q3	1130	148	1.39 (0.70, 2.77)	644	1.39 (1.20, 1.62)	197	1.73(1.33, 2.25)
Q4	989	172	1.75 (1.33, 2.30)	696	1.57 (1.35, 1.82)	262	2.25(1.74, 2.90)
	P for trend		*<0.0001*		*<0.0001*		*<0.0001*
Women							
Q1	2019	80	1.00	598	1.00	108	1.00
Q2	1935	102	1.17 (0.86, 1.59)	651	1.04 (0.91, 1.18)	117	0.94(0.71, 1.25)
Q3	1708	172	2.04 (1.54, 2.70)	732	1.14 (0.99, 1.30)	194	1.40(1.08,1.82)
Q4	1489	194	2.37 (1.78, 3.15)	782	1.13 (0.98, 1.30)	339	2.06(1.26, 3.38)
	P for trend		*<0.0001*		*0.0216*		*<0.0001*
All subjects							
Q1	3453	161	1.00	1109	1.00	203	1.00
Q2	3192	260	1.26 (0.99, 1.60)	1211	1.12 (1.01, 1.23)	260	1.16(0.82, 1.62)
Q3	2838	301	1.66 (1.16, 2.36)	1373	1.25 (1.13, 1.38)	412	1.55(1.29, 1.87)
Q4	2395	379	2.03 (1.66, 2.47)	1542	1.34 (1.09, 1.64)	608	2.18(1.83, 2.61)
	P for trend		*0.0001*		*0.0021*		*<0.0001*

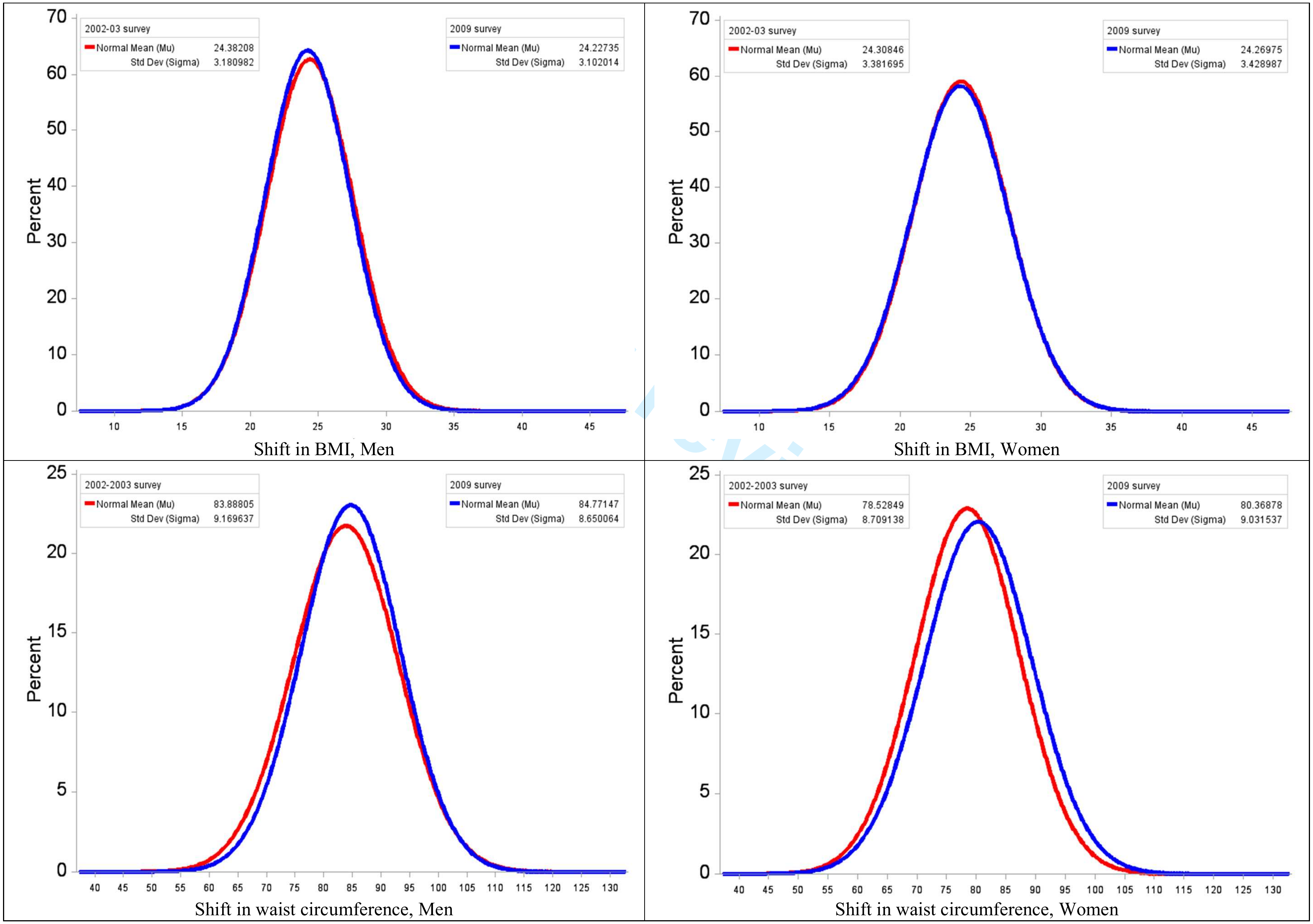
Missing value excluded from the analysis.
OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), phase of study (first /second survey); Additionally adjusted for sex (male/female) for all subjects.

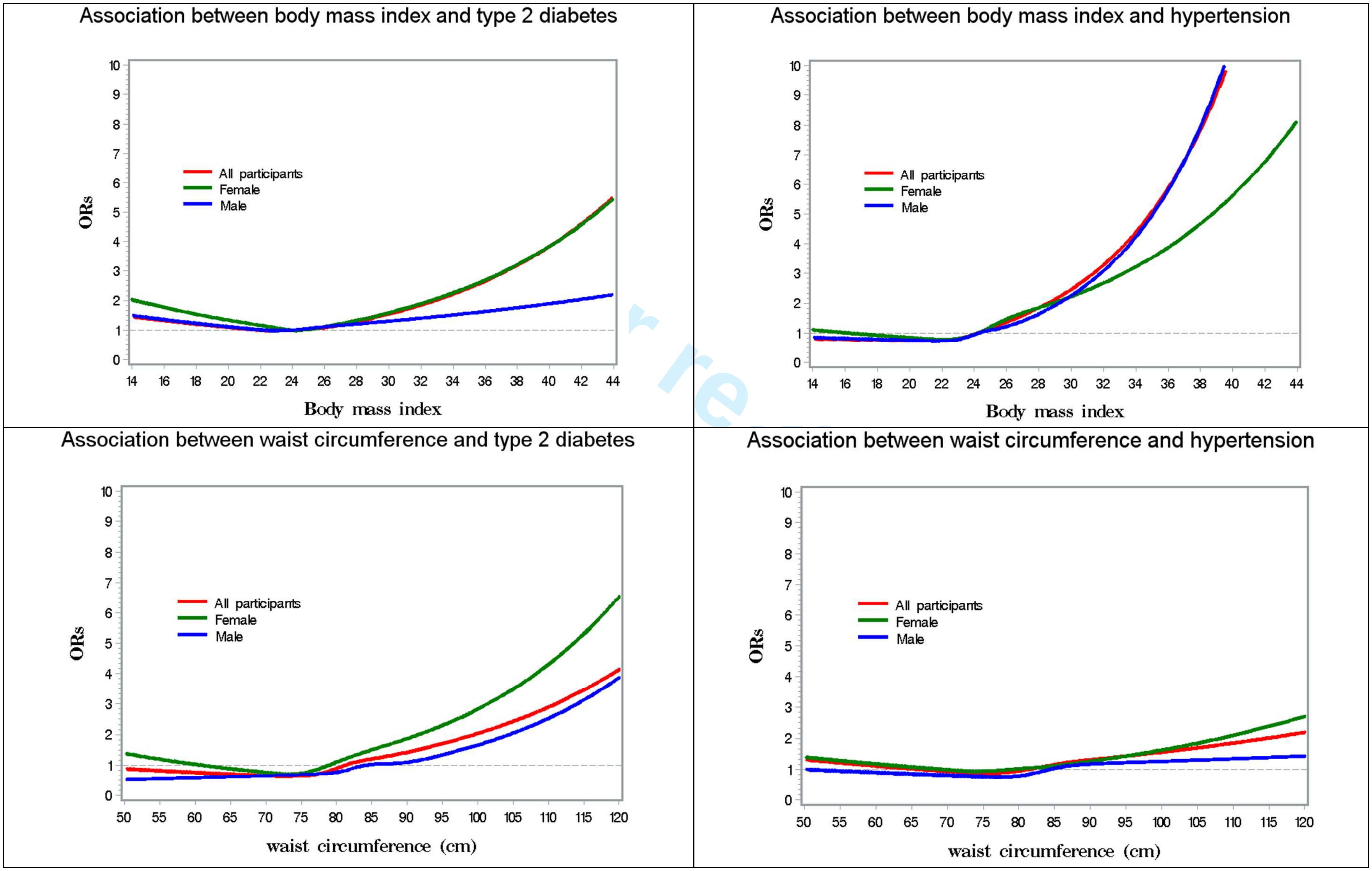
Table 4. Joint effect of general obesity and central obesity on type 2 diabetes among Chinese adults

BMI	WC：Lower			WC: Higher			OR (95%CI) for hypertension		OR (95%CI) for type 2 diabetes	
	No. of subjects	Hypertension N (%)	Diabetes N (%)	No. of subjects	Hypertension N (%)	Diabetes N (%)	WC: Lower	WC: Higher	WC: Lower	WC: Higher
Men										
<18.5	212	36	20	16	10	6	0.61(0.42, 0.89)	3.68(1.28, 10.59)	1.02(0.62, 1.67)	3.77(1.13, 12.56)
18.5-23.9	3034	767	296	679	249	111	1.00	1.56(0.94, 2.57)	1.00	1.48(1.15, 1.90)
24.0-27.9	1010	356	134	2530	1179	483	1.61(1.13, 2.32)	2.38(1.78, 3.17)	1.46(1.16, 1.83)	1.85(1.16, 2.96)
⩾28.0	36	20	4	960	580	224	3.91(1.95, 7.82)	4.67(3.97, 5.49)	1.71(0.55, 5.37)	2.60(2.12, 3.18)
						P for interaction	*0.0711*		*0.0933*	
Women										
<18.5	313	51	19	8	2	1	0.68(0.49, 0.94)	0.85(0.16, 4.51)	0.93(0.56, 1.54)	2.45(0.22, 26.72)
18.5-23.9	4323	821	265	974	314	165	1.00	1.48(1.26, 1.75)	1.00	2.36(1.89, 2.94)
24.0-27.9	1330	384	93	2724	1102	437	1.84(1.59, 2.14)	2.21(1.97, 2.49)	1.19(0.92, 1.53)	2.14(1.81, 2.54)
≥28.0	81	32	9	1467	815	317	3.10(1.93, 5.00)	4.33(3.77, 4.96)	2.14(1.01, 4.52)	3.08(2.56, 3.71)
						P for interaction	*0.3524*		*0.4011*	
Total										
<18.5	525	87	39	24	12	7	0.65(0.51, 0.83)	2.25(0.85, 5.93)	0.97(0.68, 1.39)	3.45(1.18, 10.12)
18.5-23.9	7357	1588	561	1653	563	276	1.00	1.52(1.25, 1.85)	1.00	1.88(1.42, 2.49)
24.0-27.9	2340	740	227	5254	2281	920	1.74(1.50, 2.03)	2.31(2.03, 2.62)	1.33(1.12, 1.58)	1.99(1.62, 2.45)
⩾28.0	117	5	13	2427	1395	541	3.34(2.26, 4.94)	4.46(4.02, 4.96)	2.00(1.07, 3.74)	2.85(2.49, 3.27)
						P for interaction	*0.0562*		*0.0798*	

Higher WC defined as ≥ 85 cm for men and ≥ 80 cm for women

OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), and phase of study (first /second survey).


2002-03 survey
Normal Mean (Mu) 24.38208
Std Dev (Sigma) 3.180982
2009 survey
Normal Mean (Mu) 24.22735
Std Dev (Sigma) 3.102014
Percent
Shift in BMI, Men
2002-03 survey
Normal Mean (Mu) 24.30846
Std Dev (Sigma) 3.381695
2009 survey
Normal Mean (Mu) 24.26975
Std Dev (Sigma) 3.428987
Percent
Shift in BMI, Women
2002-2003 survey
Normal Mean (Mu) 83.88805
Std Dev (Sigma) 9.169637
2009 survey
Normal Mean (Mu) 84.77147
Std Dev (Sigma) 8.650064
Percent
Shift in waist circumference, Men
2002-2003 survey
Normal Mean (Mu) 78.52849
Std Dev (Sigma) 8.709138
2009 survey
Normal Mean (Mu) 80.36878
Std Dev (Sigma) 9.031537
Percent
Shift in waist circumference, Women


Association between body mass index and type 2 diabetes
ORs
All participants
Female
Male
Body mass index
Association between body mass index and hypertension
ORs
All participants
Female
Male
Body mass index
Association between waist circumference and type 2 diabetes
ORs
All participants
Female
Male
waist circumference (cm)
Association between waist circumference and hypertension
ORs
All participants
Female
Male
waist circumference (cm)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Results of check
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	We have indicated that the study was based on two population-based cross-sectional surveys in the title and the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Line 53-62
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Line 72-87
Objectives	3	State specific objectives, including any prespecified hypotheses	Line 89-92
Methods			
Study design	4	Present key elements of study design early in the paper	Line 95-104
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Line 95-104
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Line 95-104
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Line 117-153
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Line 117-153
Bias	9	Describe any efforts to address potential sources of bias	Line 117-153
Study size	10	Explain how the study size was arrived at	NA
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Line 155-169
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Line 155-169
		(*b*) Describe any methods used to	Line 166-167

		examine subgroups and interactions	
		(*c*) Explain how missing data were addressed	There were very few missing data in this study. Please see footnote of the Table 3
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	No
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Line 95-105
		(b) Give reasons for non-participation at each stage	No information
		(c) Consider use of a flow diagram	No
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Line 172-177, and Table 1
		(b) Indicate number of participants with missing data for each variable of interest	Yes, we provide number of subjects for each variable of interest (Please see tables)
Outcome data	15*	Report numbers of outcome events or summary measures	Yes (Please see tables)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	No. Due to the large table, we present only adjusted ORs
		(*b*) Report category boundaries when continuous variables were categorized	Yes (Please see table 4)
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Line 210-217
Discussion			
Key results	18	Summarise key results with reference to study objectives	Line 219-224
Limitations	19	Discuss limitations of the study, taking into account sources of	Line 253-259

		potential bias or imprecision. Discuss both direction and magnitude of any potential bias	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Line 251-252
Generalisability	21	Discuss the generalisability (external validity) of the study results	Line 263-264
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Line 275-280

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Increased Waist Circumference and Prevalence of Type 2 Diabetes and Hypertension in Chinese Adults: Two Population-based Cross-sectional Surveys in Shanghai, China

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RUNNING HEADER: Obesity and prevalence of hypertension and T2DM in Chinese adults

Word Count:

Abstract: 249

Text: 2,658

Abstract:

Objective: To evaluate the changes in body mass index (BMI) and waist circumference (WC) and their associations with the prevalence of hypertension and type 2 diabetes (T2DM) in Chinese adults.

Design: Two consecutive population-based cross-sectional surveys.

Setting: A total of 12 districts and 7 counties in Shanghai, China.

Participants: 12,329 randomly selected participants of the survey in 2002-2003, and 7,423 randomly selected participants of the survey in 2009. All subjects were residents of Shanghai aged 35-74 years old.

Outcome measures: Measured BMI and WC. Previously-diagnosed and newly-identified hypertension and T2DM by measured blood pressure, fasting and post-load glucose.

Results: While the participants of the two surveys were comparable in BMI in each age group, the participants of the 2009 survey had significantly larger WC than those of the 2002-03 survey, with an annual percentage change (APC) being higher among subjects aged 45-49 years old in both men and women. The increase in prevalence of T2DM was observed in all age groups and also appeared more evident in subjects aged 45-49 years old. The prevalence of hypertension was observed to increase more rapidly in elderly men and middle-aged women. Obesity, both overt and central, was associated with the risk of the two diseases, but BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM.

Conclusion: The prevalence of central obesity and related chronic diseases has been increasing in Shanghai, China. Our findings provide useful information for the projection of growing burden of T2DM and hypertension in Chinese adults**.**

Keywords: type 2 diabetes; hypertension; prevalence; body mass index; waist circumference

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Article summary

Article focus

- The shift in BMI and WC among Chinese adults over past one decade.
- The contribution of changes in overall and central obesity to the increasing burden of chronic disease in China.

Key messages

- The WC increased in Chinese adults over the decade spanning 2002-2009, while BMI did not change over the same period.
- BMI was more strongly linked to hypertension while WC appeared more evidently related with T2DM in Chinese adults.
- Our findings provide useful information for the projection of a growing burden of T2DM and hypertension in Chinese adults.

Strengths and limitations of this study

- The strengths of this study include the strict process of multistage sampling in adult population of Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.
- The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM.
- The differences in several demographic characteristics between the participants of the two surveys indicate the possibility of selection bias.

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Introduction

A rising worldwide prevalence of chronic disease, manifested primarily as hypertension and type 2 diabetes (T2DM), has been well documented [1-4]. In Chinese aged 15-74 years old, the prevalence of hypertension increased from 5.11% in 1959, 7.73% in 1979 [5] and 13.58% in 1991[6] to 17.65% in 2002 [7]. The prevalence of T2DM tripled between 1980 (about 1.0%) and 1996 (3.2%) [8 9], and reached 9.7% in 2008 among adults at 20 years old or above [10]. It is estimated that over 92 million people in China have T2DM. This represents approximately half of the world's diabetic population, and places China at the "global epicenter of the diabetes epidemic" [4].

Both hypertension and T2DM are associated with obesity [11 12]. Obesity is often measured by body mass index (BMI). Across the entire range of BMI, the risk of hypertension and T2DM increases, making a higher BMI a strong predictor of both hypertension and T2DM [4 12-14]. However, a significant proportion of Asian adults diagnosed with T2DM are with the normal BMI, ie.18.5-25.0 kg/m^2 [15 16]. BMI is a general indicator of overt obesity, but does not give information about the distribution of obesity. Central obesity, often assessed via waist circumference (WC), is also strongly correlated with T2DM in both European and Asian adults [11 17]. While changes in BMI have been well documented in China over past several decades [2 18], changes in WC, and thus central obesity, are not well described.

In this study, we took advantage of the data from population based cross-sectional surveys conducted in Shanghai in 2002-03 and in 2009. We used the data from the two surveys to evaluate correlations between shifts in BMI and WC with the prevalence of hypertension and T2DM in Chinese adults. Our results may help to better understand the contribution of overall obesity and central obesity in the increasing burden of chronic disease in China.

Materials and Methods

Study Participants

A representative sample of the general population was randomly selected through a multistage sampling process in the 2002-03 survey. Firstly, 4 districts and 2 counties were randomly selected

from a total of 12 districts and 7 counties in Shanghai, China. And then, 1-2 sub-districts or towns were randomly selected from each selected district or county. Next, 1-2 communities or villages, usually 1,000-2,000 residents for each, were randomly selected from each selected sub-district or town. Finally, eligible subjects (permanent residents of Shanghai, 15-74 years old and having been in the city for at least 5 years) were randomly selected from the selected communities and villages and were invited for participation. Pregnant women, individuals with type I diabetes, and physically or mentally disabled persons were excluded from the participation. During the period of May 2002-October 2003, a total of 17,526 eligible subjects were recruited, and 14,401 (82.17%) participated the survey.

The 2009 survey used the similar sampling method except that only 7 communities and villages were randomly selected in the third stage of sampling. The inclusion and exclusion criteria of the 2009 survey were also similar to those for the 2002-03 survey, except that only those at the age of 35-74 years old were eligible for the 2009 survey. Among 7,627 eligible adults contacted during the period of May-July 2009, 7,414 (97.21%) were interviewed and donated blood samples.

To make the two surveys comparable, we excluded 1,071 subjects younger than 35 years from the 2002-03 survey. After further excluding subjects with missing information, the final analysis included 5,050 men and 7,279 women in the 2002-03 survey and 3,461 men and 3,962 women in the 2009 survey. The Institutional Review Board at Shanghai Municipal Center of Disease Control and Prevention approved the study. Informed consent was obtained from each participant before data collection and laboratory measurements.

Data Collection

A similar survey approach was followed by the two investigations. In both surveys, information on demographic and socioeconomic factors, diagnosis of diabetes, tobacco and alcohol use, physical activity and family history of diabetes was collected by trained interviewers with a structured questionnaire at community clinics located in the residential areas of the participants.

At the interview, each participant's blood pressure, body weight, standing height, and waist

circumference (WC) were measured by trained staff. Blood pressure was measured on the right arm in the sitting position using standard mercury sphygmomanometer after at least 5 minutes of rest. The first and fifth Korotkoff sounds were recorded. Body weight and height were recorded while the subject was in light clothing and without shoes. Body weight was measured with electronic scales to the nearest 0.1 kg. Body height was measured to the nearest 0.1 cm by using a stadiometer. WC, recorded to the nearest 0.1 cm, was taken with a cloth tape and was measured on bare skin at the midline between the lower border of the ribs and the iliac crest in the horizontal plane after a normal expiration. Two measurements were taken and the mean of the replicates was used in the following analyses. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2) using the direct measurements.

Laboratory Measurements

After at least 10 hours of overnight fasting, 1-1.5 ml venous blood specimen was collected in a vacuum tube containing sodium fluoride. All participants with no history of diabetes and having a fasting plasma glucose level of < 7.0 mmol per liter (mmol/l) were then asked to have an oral glucose-tolerance test (OGTT). Blood samples were drawn at 0 and 120 minutes after a standard 75 gram glucose load. Plasma glucose was measured with Glucose oxidase-peroxidase (GOD-PAP) method.

Diagnosis of T2DM and Hypertension

Previously diagnosed T2DM and hypertension was identified by a positive response from the participant to the question of "Have you ever diagnosed with T2DM/hypertension by a doctor?" and confirmed by medical records in which prescriptions of anti-hypertensive or hypoglycemic medications were presented. The consistent rate was 100%. For those who had a negative response, the T2DM was diagnosed with measured glucose level by using the 1999 World Health Organization diagnostic criteria [Department of Noncommunicable Disease Surveillance. Definition, diagnosis and classification of diabetes mellitus and its complications: report of a WHO consultation. Part 1. Diagnosis and classification of diabetes mellitus. Geneva: World Health

Organization, 1999. (Accessed July 5, 2010, at http://www.staff.ncl.ac.uk/philip.home/who_dmg.pdf.)] and hypertension referred to the subjects with measured systolic blood pressure (SBP) ≥ 140 mmHg or diastolic blood pressure (DBP) ≥ 90 mmHg and confirmed by clinical visits. Total T2DM and hypertension included both previously diagnosed and newly-diagnosed patients. 42.7% (1,110 of 2,598) diabetic patients and 10.3% (694 of 6,735) hypertensive patients were newly-diagnosed in the two surveys.

Statistical Analysis

SAS software 9.2 was used for all the statistical analyses. Characteristics of the subgroups were described using summary statistics (median, 25^{th} and 75^{th} percentile, frequencies, and percentages) separately for men and women. The differences between two surveys were compared using χ^2 test (category variables) and Wilcoxon tests (continuous variables). The annual percentage changes (APC) in prevalence between two surveys were calculated as (prevalence in 2009 – prevalence in 2002-03) / number of years using logarithms for each age group. Percentile curves were constructed for BMI and WC values in the two surveys by gender using the LMS (lambda, mu, sigma) method. Restricted cubic splines (RCS) were used to model a potential curvilinear relationship of BMI and WC with hypertension and diabetes using the 5^{th}, 25^{th}, 75^{th} and 95^{th} percentiles as fixed knots and the 50^{th} percentile as the reference. Polynomial logistic regression were used to estimate the odds ratios (OR) and 95% confidence intervals (95% CI) of BMI and WC with T2DM and hypertension. Meta-analysis was applied to obtain the combined ORs and 95% CI considering the potential heterogeneity of the populations in the two surveys. The residual method was used to derive the independent effect of BMI and WC with each other in the models. *P* value less than 0.05 was considered as a test of significance based on two sides.

Results

The male participants in two studies were similar in age, resident site and cigarette smoking while the female participants were comparable in cigarette smoking ($P > 0.05$) (Table 1). Compared to the subjects in 2002-03 survey, the participants of 2009 survey, both men and women, had lower level of education, higher level of income per capita, more prior history of T2DM, higher frequency of alcohol drinking and lower frequency of leisure time activity, and were more likely to have a family history of diabetes.

Figure 1 shows the shapes of the BMI and WC distribution curves among men and women changed over the period of the two surveys. After adjusting for age, education, per capita income, resident site, smoking, drinking, regular exercise, and family history of T2DM, the curves of BMI were almost overlapped in both men and women. However, the WC curves for men and women were shifted to the right between 2002-03 and 2009, with the mean WC increasing from 83.6 to 85.3 cm for men and from 78.4 to 80.6 cm for women.

As presented in table 2, the prevalence of obesity, both overall and central, increased with increasing age groups. While the prevalence of overall obesity (BMI ≥ 28 kg/m^2) did not change between two surveys (all P values > 0.05), the prevalence of central obesity was significantly higher in 2009 survey in each age group (all P values < 0.001). A more pronounced increase in the prevalence of central obesity and T2DM was observed among subjects aged 45-49 years old in both men and women; whereas the change in the prevalence of hypertension between two surveys appeared more evident in older men and younger women over the period. Using the World Health Organization (WHO) criteria for obesity did not change the results substantially (data not shown in the tables).

BMI and WC were highly correlated with each other, with a correlation coefficient of 0.77 (P < 0.0001) among men and 0.78 (P < 0.0001) among women after adjusting for age. Therefore, the residual method was used to test the potential respective non-linear relationships of BMI and WC with the risk of T2DM and hypertension (Figure 2). The dose-response analysis likewise showed a statistically significant increased risk of T2DM at high level of WC and a significant elevated risk of hypertension at high level of BMI in both men and women after adjusting for age, education, per capita income, resident site, smoking, alcohol consumption, regular exercise, family history of T2DM and phase of surveys, with P values for non-linear relationship tests < 0.05. No significant relationship was observed between BMI and T2DM in men and between WC and hypertension in women.

As shown in table 3, in both sexes, BMI adjusted for WC (residuals) appeared more strongly associated with hypertension while WC adjusted for BMI (residuals) was more evidently related with T2DM. Comparing with the lowest quartile of BMI residuals, the risk of hypertension increased 85% (95%CI: 1.59-2.15) in men and 1.23-fold (95%CI: 1.94-2.57) in women, whereas the risk of T2DM did not increase significantly in both sexes. On the other hand, the ORs of the highest versus the lowest quartile WC residuals for T2DM were 1.75 (95%CI: 1.33-2.30) in men and 2.37 (95%CI: 1.78-3.15) in women, higher than the OR of 1.57 (95%CI: 1.35-1.82) in men and 1.13 (95%CI: 0.98-1.30) in women for hypertension.

We further evaluated the potential joint effect of BMI and WC on T2DM and hypertension (table 4). The participants were classified into normal weight (BMI 18.5-23.9 kg/m^2), overweight (24.0-27.9 kg/m^2), or obese (≥ 28 kg/m^2) based on data from Chinese adults, and were defined as with normal or increased WC using sex-specific cut-offs (85 cm in men and 80 cm in women) [19]. The risk of T2DM and hypertension increased across groups defined by BMI and WC, with the highest risk observed among men with the lowest BMI but a higher WC, and among those with the highest BMI and a higher WC for hypertension. However, no significant interaction was observed between BMI and WC (all *P* values for interaction tests > 0.05).

Discussion

In this representative sample of the adult population in Shanghai, the largest city in China, we observed an increased prevalence of central obesity, hypertension and T2DM over the decade spanning 2002-2009. In contrast, BMI did not change over the same period. Our results present a snapshot of overt versus central obesity in the Chinese population and suggest that the epidemic of central obesity in this population, which has been more closely associated with the prevalence of T2DM, may lead to a more rapidly growing burden of T2DM in China.

Chinese adults have lower rates of overweight and obesity than their Western counterparts using the WHO criteria (BMI ≥ 25 kg/m^2 for overweight and BMI ≥ 30 kg/m^2 for obesity) [15 16]. Nevertheless, increasing trends of BMI in Chinese adults have been well documented [18 20]. In two national nutritional surveys undertaken in 1982 and 1992 in China, the prevalence of overweight/obesity (BMI ≥ 25 kg/m^2) in subjects 20-70 years of age was 10% and 15%, respectively. Between 1992 and 2002, the combined prevalence of overweight and obesity increased from 14.6 to 21.8% [21]. Interestingly, the increase in BMI among Chinese adults has slowed down during past decades [2]. In this study, we did not observe an increase in BMI and prevalence of obesity defined by the Chinese obesity standards or by WHO criteria (data not shown). Instead, we observed a significant increase in WC, a measure of central obesity between surveys. Our observation of increased WC in Chinese adults, without a concomitant increase in BMI, represents an increasing burden of central obesity in this population. The increase in central obesity indicates an upward trend in body fat percentages in the population who have been previously observed with higher body fat percentages compared to other ethnic people with the same BMI [22 23].

Both epidemics of overall and central obesity parallel a continuously increasing prevalence of hypertension and T2DM in China [21]. Several studies indicate that overall obesity (BMI) is more strongly associated with hypertension, while central obesity (WC) is more strongly associated with T2DM [17 24-26]. The rationale for these associations is based on the notion that central obesity reflects specific accumulation of visceral adipose tissue. Excess visceral adipose tissue is metabolically unfavorable due to productions of free fatty acids and inflammatory mediators. Overall obesity, on the other hand, represents a greater overall physiologic strain and effects vascular and cardiac parameters more significantly. In this study, we observed a significant increase in prevalence of T2DM regardless of gender or age groups, which was more pronounced than the change in the prevalence of hypertension during the period of 2002-03 and 2009. We also observed a closer association of central obesity with the prevalence of T2DM than with the prevalence of hypertension. These results support the notion that central obesity in particular is a stronger risk factor for T2DM than for hypertension in Chinese adults. Due to the cross-sectional design, however, our study was unable to make a causal inference.

The nature of the cross-sectional study design limits our ability to directly evaluate the influence of overall and central obesity as well as the change of their prevalence on the risk of hypertension and T2DM. The differences in several demographic characteristics between the participants of the two surveys indicate the changes in general population over time. However, selection bias could not be excluded. There are several strengths in this study, including the strict process of multistage sampling in adult population in Shanghai, anthropometric measurement according to a standardized protocol and fasting and postprandial blood glucose tests for the participants.

Conclusions

In summary, this study describes the potential association of central obesity with an upward trend of T2DM. Our findings provide useful information about the growing burden of type 2 diabetes and hypertension in Chinese adults and suggest the need for further study in other rapidly changing populations in China.

Acknowledgements

We thank Dr. Xiao-ou Shu and Dr. Hui Cai of Vanderbilt University for their contributions in study design and data analysis. The authors thank the study participants of the two cross-sectional surveys and the healthcare workers in each community involved.

Footnotes

Contributors YR and MM contributed to data collection, data analysis and draft of the paper. YR, YYL, QDY, and LS contributed to data collection and quality control. LJM contributed to revision of the paper. HZ contributed to data clean and analysis. RL and WHX contributed to study design, statistical analysis and revision of the paper. All authors contributed to the interpretation of data and revision of the manuscript. All authors approved the final version.

Funding This study was supported by the Key Program of Shanghai Municipal Committee of Science and Technology (04 DZ19502), the Shanghai Medical Development Program (01ZD001) and the Shanghai Municipal Health Bureau (GWDTR201204). W. H. Xu was supported by a training grant from the Fogarty International Center (D43 TW008313 to X. O. Shu). The funders had no role in study design, data collection or analysis, decision to publish, or preparation of the manuscript.

Conflict of Interest: None declared.

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Figure 1. Shift in BMI and WC over the period of the two population-based surveys

Figure 2. Non-linear dose-response relationship of BMI and WC with hypertension and T2DM among participants of the two population-based surveys

Table 1. Characteristics of participants in two population-based surveys in Shanghai, China

Characteristics	1st survey		2nd survey		*P-value between surveys* [a]	
	Men (N=5,050)	Women (N=7,279)	Men (N=3,461)	Women (N=3,962)	*In men*	*In women*
Age (yrs., mean ± SD)	54.8 ± 10.8	53.1 ± 10.3	54.7 ± 9.5	54.7 ± 9.1	0.55	<0.0001
Resident site (%)						
Urban	71.1	63.0	72.4	72.0		
Rural	29.0	37.0	27.7	28.0	*0.19*	*<0.0001*
Education (%)						
No formal education	4.1	18.4	3.2	9.5		
Primary school	18.2	23.0	14.7	17.7		
Middle school	35.3	31.1	45.7	45.2		
High school	27.6	22.6	27.6	23.8		
Colleague or above	14.8	4.9	8.8	3.9	*0.0025*	*<0.0001*
Per capita income (yuan/mo.) (%)						
<1000	37.0	45.5	4.9	4.0		
1000-2999	38.3	38.4	41.8	46.7		
3000-5000	22.5	17.9	33.2	33.3		
>5000	2.2	1.3	20.0	16.0	*<0.0001*	*<0.0001*
Family history of type 2diabetes	12.3	13.1	16.4	19.0	*<0.0001*	*<0.0001*
Prevalence of type 2diabetes (%)	13.6	10.3	17.4	14.1	*<0.0001*	*<0.0001*
Prevalence of hypertension (%)	34.8	28.3	41.8	37.1	*<0.0001*	*<0.0001*
Cigarette smoking (%)	61.4	1.7	62.6	1.8	*0.22*	*0.93*
Alcohol drinking (%)	40.4	2.4	54.0	5.0	*<0.0001*	*<0.0001*
Leisure-time activity (%)	13.3	13.1	10.8	9.0	*0.0009*	*<0.0001*

[a] *P* for Wilcoxon tests or chi-square tests

Table 2. Prevalence of obesity, hypertension and type 2 diabetes in participants of the two population-based surveys by age groups in Shanghai, China

	No. of subjects		Overall Obesity		APC	Central obesity		APC	Hypertension		APC	Type 2 diabetes		APC
	1st survey	2nd survey	1st survey	2nd survey	(%)	1st survey	2nd survey	(%)	1st survey	2nd survey	(%)	1st survey	2nd survey	(%)
Men														
Overall	5050	3461	11.7	11.9	*0.21*	46.3	53.8	*2.35*	34.8	41.8	*2.87*	13.6	17.4	*3.78*
Age-groups														
35-	414	230	10.5	9.1	*-2.11*	41.8	45.2	*1.22*	15.2	11.7	*-3.92*	4.6	5.7	*3.25*
40-	574	302	10.0	8.3	*-2.83*	41.8	47.00	*1.85*	22.5	21.9	*-0.43*	7.8	7.6	*-0.44*
45-	837	445	12.6	12.6	*-0.04*	44.0	53.7	*3.12*	25.3	31.0	*3.16*	7.8	13.7	*9.13*
50-	833	739	12.2	10.8	*-1.76*	44.1	53.8	*3.12*	33.1	40.3	*3.07*	12.7	18.3	*5.72*
55-	628	669	10.4	13.2	*3.78*	47.3	54.6	*2.25*	35.4	45.6	*3.99*	15.0	17.9	*2.82*
60-	507	513	10.5	15.4	*6.18*	48.7	56.1	*2.19*	44.6	51.7	*2.29*	15.6	20.1	*3.98*
65-	674	313	12.6	11.8	*-0.99*	51.4	61.0	*2.67*	49.4	59.4	*2.88*	20.8	26.2	*3.64*
70-	583	250	13.8	9.6	*-5.40*	51.1	54.0	*0.85*	50.9	65.2	*3.87*	24.2	25.6	*0.88*
Women														
Overall	7279	3962	13.8	13.8	*0.02*	41.7	54.2	*4.10*	28.3	37.1	*4.28*	10.3	14.1	*4.84*
Age-groups														
35-	615	251	7.5	7.2	*-0.65*	22.6	26.3	*2.35*	6.8	10.8	*7.24*	3.3	4.0	*3.17*
40-	1000	287	9.4	11.2	*2.66*	27.6	38.0	*5.05*	11.7	15.7	*4.61*	4.1	5.9	*5.81*
45-	1491	563	11.0	9.8	*-1.82*	32.3	42.6	*4.38*	19.3	23.5	*3.03*	5.8	8.7	*6.32*
50-	1309	866	15.1	14.1	*-1.00*	43.9	54.0	*3.24*	28.7	31.0	*1.16*	8.3	9.4	*1.94*
55-	838	818	15.7	13.6	*-2.17*	47.5	60.6	*3.83*	33.9	39.7	*2.48*	8.8	15.3	*8.80*
60-	610	585	19.2	18.1	*-0.87*	53.5	63.1	*2.58*	40.5	52.8	*4.17*	16.7	19.2	*2.11*
65-	799	327	18.0	18.4	*0.28*	59.0	66.1	*1.76*	48.4	59.3	*3.17*	23.7	27.8	*2.54*
70-	617	265	18.2	16.6	*-1.36*	60.2	68.7	*2.05*	51.4	64.5	*3.57*	21.4	27.2	*3.75*
All subjects														
Overall	12329	7423	13.0	12.9	*-0.05*	43.6	54.0	*3.35*	31.0	39.3	*3.75*	11.7	15.6	*4.53*
Age-groups [a]														
35-	1029	481	8.7	8.0	*-1.04*	30.3	33.9	*2.39*	10.2	11.2	*1.49*	3.8	4.7	*3.63*
40-	1574	589	9.6	10.1	*0.11*	32.7	41.3	*4.14*	15.6	17.9	*2.92*	5.5	6.5	*3.41*
45-	2328	1008	11.6	10.8	*-0.77*	36.5	46.6	*4.16*	21.5	26.2	*3.46*	6.5	10.5	*8.22*
50-	2142	1605	13.9	12.8	*-1.53*	44.0	53.9	*3.19*	30.4	34.6	*0.90*	10.0	12.8	*4.69*
55-	1466	1487	13.4	13.4	*0.01*	47.4	58.1	*3.13*	34.5	42.2	*3.20*	11.5	16.4	*5.75*
60-	1117	1098	15.2	16.9	*1.59*	51.3	59.9	*2.39*	42.4	52.3	*3.29*	16.2	19.6	*2.96*
65-	1473	640	15.6	15.4	*-0.39*	55.5	63.8	*2.11*	48.9	59.4	*3.04*	22.3	27.1	*2.98*
70-	1200	515	16.0	13.2	*-2.94*	55.8	61.5	*1.52*	51.2	64.9	*3.71*	22.8	26.4	*2.32*

[a] adjusted for sex according to the distribution in the first survey.

Table 3. Association of body size with hypertension and type 2 diabetes in two population-based surveys in Shanghai, China

	No. of subjects with neither diseases	Type 2 diabetes only		Hypertension only		Both	
		N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
BMI residuals							
Men							
Q1	1260	156	1.00	529	1.00	175	1.00
Q2	1224	142	0.99 (0.77, 1.27)	583	1.16 (1.00, 1.34)	172	1.11(0.87, 1.41)
Q3	1164	132	1.09 (0.84, 1.41)	651	1.50 (1.29, 1.74)	171	1.36(1.07, 1.73)
Q4	1079	123	1.16 (0.88, 1.51)	709	1.85 (1.59, 2.15)	207	1.95(1.54, 2.47)
	P for trend		*0.2472*		*<0.0001*		*<0.0001*
Women							
Q1	1816	166	1.00	600	1.00	223	1.00
Q2	1866	148	1.02 (0.80, 1.29)	629	1.29 (1.12, 1.48)	162	0.96(0.77, 1.21)
Q3	1835	125	0.89 (0.69, 1.15)	687	1.51 (1.31, 1.73)	158	1.03(0.82, 1.31)
Q4	1634	109	0.94 (0.73, 1.23)	847	2.23 (1.94, 2.57)	215	1.85(1.15, 2.98)
	P for trend		*0.4864*		*<0.0001*		*0.0067*
All subjects							
Q1	3048	330	1.00	1162	1.00	385	1.00
Q2	3079	282	1.00 (0.84, 1.19)	1200	1.22 (1.11, 1.35)	363	1.03(0.87, 1.22)
Q3	2998	278	0.98 (0.82, 1.18)	1346	1.50 (1.36, 1.67)	302	1.18(1.00, 1.40)
Q4	2753	211	1.04 (0.86, 1.26)	1527	2.05 (1.85, 2.27)	433	1.88(1.60, 2.21)
	P for trend		0.2280		*<0.0001*		*<0.0001*
WC residuals							
Men							
Q1	1376	102	1.00	531	1.00	111	1.00
Q2	1232	131	1.34 (1.02, 1.78)	601	1.23 (1.06, 1.42)	155	1.41(1.07, 1.84)
Q3	1130	148	1.39 (0.70, 2.77)	644	1.39 (1.20, 1.62)	197	1.73(1.33, 2.25)
Q4	989	172	1.75 (1.33, 2.30)	696	1.57 (1.35, 1.82)	262	2.25(1.74, 2.90)
	P for trend		*<0.0001*		*<0.0001*		*<0.0001*
Women							
Q1	2019	80	1.00	598	1.00	108	1.00
Q2	1935	102	1.17 (0.86, 1.59)	651	1.04 (0.91, 1.18)	117	0.94(0.71, 1.25)
Q3	1708	172	2.04 (1.54, 2.70)	732	1.14 (0.99, 1.30)	194	1.40(1.08,1.82)
Q4	1489	194	2.37 (1.78, 3.15)	782	1.13 (0.98, 1.30)	339	2.06(1.26, 3.38)
	P for trend		*<0.0001*		*0.0216*		*<0.0001*
All subjects							
Q1	3453	161	1.00	1109	1.00	203	1.00
Q2	3192	260	1.26 (0.99, 1.60)	1211	1.12 (1.01, 1.23)	260	1.16(0.82, 1.62)
Q3	2838	301	1.66 (1.16, 2.36)	1373	1.25 (1.13, 1.38)	412	1.55(1.29, 1.87)
Q4	2395	379	2.03 (1.66, 2.47)	1542	1.34 (1.09, 1.64)	608	2.18(1.83, 2.61)
	P for trend		*0.0001*		*0.0021*		*<0.0001*

Missing value excluded from the analysis.
OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), phase of study (first /second survey); Additionally adjusted for sex (male/female) for all subjects.

Table 4. Joint effect of general obesity and central obesity on type 2 diabetes among Chinese adults

BMI	WC：Lower			WC: Higher			OR (95%CI) for hypertension		OR (95%CI) for type 2 diabetes	
	No. of subjects	Hypertension N (%)	Diabetes N (%)	No. of subjects	Hypertension N (%)	Diabetes N (%)	WC: Lower	WC: Higher	WC: Lower	WC: Higher
Men										
<18.5	212	36	20	16	10	6	0.61(0.42, 0.89)	3.68(1.28, 10.59)	1.02(0.62, 1.67)	3.77(1.13, 12.56)
18.5-23.9	3034	767	296	679	249	111	1.00	1.56(0.94, 2.57)	1.00	1.48(1.15, 1.90)
24.0-27.9	1010	356	134	2530	1179	483	1.61(1.13, 2.32)	2.38(1.78, 3.17)	1.46(1.16, 1.83)	1.85(1.16, 2.96)
⩾28.0	36	20	4	960	580	224	3.91(1.95, 7.82)	4.67(3.97, 5.49)	1.71(0.55, 5.37)	2.60(2.12, 3.18)
						P for interaction	*0.0711*		*0.0933*	
Women										
<18.5	313	51	19	8	2	1	0.68(0.49, 0.94)	0.85(0.16, 4.51)	0.93(0.56, 1.54)	2.45(0.22, 26.72)
18.5-23.9	4323	821	265	974	314	165	1.00	1.48(1.26, 1.75)	1.00	2.36(1.89, 2.94)
24.0-27.9	1330	384	93	2724	1102	437	1.84(1.59, 2.14)	2.21(1.97, 2.49)	1.19(0.92, 1.53)	2.14(1.81, 2.54)
≥28.0	81	32	9	1467	815	317	3.10(1.93, 5.00)	4.33(3.77, 4.96)	2.14(1.01, 4.52)	3.08(2.56, 3.71)
						P for interaction	*0.3524*		*0.4011*	
Total										
<18.5	525	87	39	24	12	7	0.65(0.51, 0.83)	2.25(0.85, 5.93)	0.97(0.68, 1.39)	3.45(1.18, 10.12)
18.5-23.9	7357	1588	561	1653	563	276	1.00	1.52(1.25, 1.85)	1.00	1.88(1.42, 2.49)
24.0-27.9	2340	740	227	5254	2281	920	1.74(1.50, 2.03)	2.31(2.03, 2.62)	1.33(1.12, 1.58)	1.99(1.62, 2.45)
⩾28.0	117	5	13	2427	1395	541	3.34(2.26, 4.94)	4.46(4.02, 4.96)	2.00(1.07, 3.74)	2.85(2.49, 3.27)
						P for interaction	*0.0562*		*0.0798*	

Higher WC defined as ≥ 85 cm for men and ≥ 80 cm for women
OR: Adjusted for age (continuous variable), education (no formal education, primary school, middle school, high school, colleague or above, dummy variables), per capita income (<1000, 1000-2999, 3000-5000 and >5000 RMB Yuan / month, dummy variables), resident site (urban/rural area), family history of type 2 diabetes (yes/no), smoking (ever/never), alcohol drinking (ever/never), regular exercise (never/ever), and phase of study (first /second survey).