Association of General and Central Adiposity with Blood Pressure among Chinese adults: Results from the China National Stroke Prevention Project (CSPP)

Running title: Adiposity and blood pressure

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Abstract

Background: The American Heart Association recommended that waist circumference was a better predictor of blood pressure risk than body mass index in Asians. However, data are inconsistent and information in Chinese, the largest global population group, is limited.

Methods: Data was obtained from the Chinese National Stroke Prevention Project Survey of a nationally representative sample of middle-aged and older Chinese adults. A total of 135825 individuals not taking any antihypertensive drugs were included in this study. Multiple linear regression analyses were conducted to examine the association between blood pressure and parameters of general adiposity, including body mass index, height-adjusted weight, and parameters of central adiposity, including waist circumference, hip circumference, waist-hip ratio, and waist-height ratio. Results were shown as mean difference in blood pressure associated with one standard deviation higher level of adiposity.

Results: The overall means±standard deviation of BMI and waist circumference were 24.3±3.18 kg/m and 84.0±8.88 cm, respectively. BMI seemed more strongly associated with SBP/DBP (4.22 mmHg/SD; 2.60 mmHg/SD) than central adiposity markers. In addition, there were sex differences. For men, waist circumference showed a stronger association with SBP/DBP than BMI (4.04 vs. 3.79, $P<0.05$; 2.26 vs. 2.13, $P<0.05$). For women, BMI was more closely related to SBP/DBP than central adiposity parameters, such as waist circumference (4.59 vs. 3.41, $P<0.05$; 2.98 vs. 2.24, $P<0.05$). Additionally, in both urban and rural areas, waist circumference was mostly associated with SBP/DBP among men, whereas it was BMI among women.

Conclusions: Compared with central adiposity, blood pressure is more strongly associated with general adiposity in Chinese adults. Interestingly, there are significant sex differences in the relationship of blood pressure with general and central adiposity. Waist circumference is the strongest predictor for men but suboptimal for women, and BMI tend to a better predictor of blood pressure for women. In addition, our results for men are consistent with the recommendation of the American Heart Association in 2015 that waist circumference could be used for assessing the risk of blood pressure.

Keywords: general adiposity; central adiposity; blood pressure; China

Introduction

High blood pressure (BP) is a major cause of coronary heart disease and stroke, and contributes to morbidity and premature mortality in both developed and developing countries [1-4]. The causes of high BP are complex and are correlated with numerous environmental and genetic factors. Among them, adiposity is a well-established modifiable risk factor [5-7]. Previous studies have reported that body mass index (BMI), a general measure of adiposity, is a predictor of BP [8-9]. Subsequently, a growing amount of evidence has indicated that central adiposity parameters, such as waist circumference (WC), hip circumference (HC), waist-hip ratio (WHR), and waist-to-height ratio (WHtR), are also related to BP [10-11]. Several studies have investigated the association of different measures of central and general adiposity with BP, but findings have been inconsistent. Some studies tended to suggest that WC is more strongly associated with BP as compared to BMI [8-9]. But others did not support this, showing that BMI was a better predictor of BP than WC [12-13]. Moreover, the majority of existing studies were conducted in Western populations [14-15]. China has the largest population in the world (with one-fifth of the world's population)， but there has been no research based on a nationally representative adult sample in China. Additionally, great differences in genetic backgrounds and the criteria for evaluating obesity by BMI exist between Chinese and Western populations [16]. A good understanding of associations between BP and different measures of general obesity or central adiposity in China is of particular importance, which may not only help to inform public health policies for the control of high BP and related cardiovascular diseases, but also provide valuable evidence on the topic in the international cardiovascular diseases -related research field.

Although BMI has been used to measure adiposity in many countries including Asians, its sensitivity was low in the assessment of the risk of cardiovascular disease [17]. In 2015, the American Heart Association (AHA)recommended that the WC should be used to assess the risk of cardiovascular diseases in Asians [17]. Studies have shown that control of blood pressure could reduce the risk of cardiovascular disease [18-19], and recent studies have reported that WC was associated with BP [20-21]. However, these studies mainly focused on the relationship between WC and BP in western population and Chinese children. Research in a nationally representative sample of Chinese adults has not been available.

The present study aimed to evaluate the association between BP and different measures of general or central obesity based on data from a national population-based study of Chinese adults.

Subjects and Methods

Study population and sampling

The China National Stroke Prevention Project (CSPP) was a national campaign on stroke prevention and control launched in 2011 by the Chinese government. The CSPP survey was carried out in 30 provinces of China from September 2014 to May 2015, administered by the National Project Office of CSPP. The CSPP survey used a two-stage stratified cluster sampling method. At the first stage, 200 project areas were determined in proportion to the local population size and numbers of total counties. At the second stage, an urban community and a rural village were selected as primary sampling units according to geographical location and suggestions from local hospitals. The cluster sampling method was used in every primary sampling unit, and all residents aged 40 years or older were surveyed during the primary screening. A total of 849,874 adults aged ≥40 years were registered at the local government office. Of these adults, 726,451 received the stroke screening, yielding a response rate of 85.48%. Questionnaire completion and the assessment of stroke risk factors were conducted in primary health care institutions. About 180000 subjects were selected randomly for further assessment of blood pressure and physical examination.

Written informed consent was obtained from all individuals, and the study protocol was approved by the Ethics Committee of the Xuanwu Hospital Institutional Review Board, Capital Medical University (Beijing, China).

Date collection

Data collection was conducted by trained medical staff using a structured questionnaire in community health centers. Information obtained included sociodemographic characteristics, lifestyle factors (including physical activity, smoking and alcohol consumption), and medical history. The senior investigators checked the completed questionnaires daily as a quality control measure. Data were entered into a database in a double-blind manner by two researchers using EpiData 3.0.

Blood pressure measurement

Subjects sat quietly in a chair with their back supported, both feet flat on the floor, and arms supported at the heart level during blood pressure measurement. A trained nurse used an automated Sphygmomanometer to measure blood pressure. Three measurements were taken in the morning between 08:00 and 09:00 am at 5-min intervals after a 20-min rest. We used the mean values of the three recorded measurements for the analysis. Considering that systolic blood pressure（SBP）is a better predictor of vascular mortality than diastolic blood pressure (DBP), SBP was used in the main analyses. [22] Results for DBP were provided in a supplementary file.

Body adiposity measures

The anthropometric indices were measured using standard techniques and equipment with the subjects in light clothing after an overnight fast. Height was measured by a portable stadiometer to within 0.1cm without shoes. Weight was measured using a digital scale to within 0.1 kg without heavy outer garments. WC was measured at the midpoint between the iliac crest and the lower rib, and HC was measured at the widest circumference over the gluteal muscles. Both WC, and HC were measured to the nearest 0.1 cm.

Covariate variables

Physical activity was defined as ≥3 times per week for at least 30 minutes each time, or engaged in heavy physical work. Low level of physical activity refers to the action of rare exercise or light physical work lasting for more than 1 year, during which the exercise is done for less than 30mins each time and less than 3 times a week. Smoking was defined as smoking ≥1 cigarette per day in the last 3 months. Drinking was defined as alcohol drinking at least once per week for more than half a year.

Statistical analysis

The present study assessed six adiposity variables either directly measured or derived, including two general and four central adiposity measurements. The two anthropometric markers of general adiposity are height-adjusted weight (HtaW) and BMI, and the four anthropometric markers of central adiposity are WC, HC, WHR, and WHtR. BMI was calculated as weight (in kilograms) divided by height (in meters) squared. WHR was calculated as WC divided by HC, and WHtR was WC divided by height.

To control measurement errors, individuals with implausible values of adiposity measures (e.g. BMI <15 or >50 kg/m^2; n=699) and blood pressures (SBP <80 or >250 mm Hg; DBP <40 or >150 mm Hg; n=97) or missing data (n=758) were excluded. We also excluded participants currently taking antihypertensive drugs (42926). Finally, a total of 135825 participants remained in the analysis.

Categorical data were described as percentages and continuous data were described as means ± standard deviation (SD). All continuous data was abnormally distributed even after logarithmic transformation using a Shapiro-Wilk test. Differences in the distribution of baseline characteristics between males and females were tested using a Student's t-test for continuous variables (age, height, weight, BMI, WC, HC, WHR, WHtR, SBP and DBP) and a chi-square test for categorical variables (smoking, drinking status and physical activity). We used multiple linear regression to estimate the mean difference in SBP and DBP associated with a 1 SD higher level of adiposity. In the multiple linear regression analysis, covariates included age (year in continuous), smoking status (yes, no), alcohol consumption (yes, no) and physical activity (yes, no). All statistical analyses were performed using SPSS19.0 (SPSS Inc, Chicago, Ill)， and Stata 13.0. A value of P＜0.05 was considered as statistically significant.

Results

Of the 135825 individuals remained in the final analysis, there were 62451 men (mean age, 58±11years) and 73374 women (mean age, 59±10 years). Demographic, lifestyle, and anthropometric characteristics stratified by gender of the overall sample and final participants are shown in Table 1. The 135825 subjects had a mean BMI of 24.3±3.18 kg/m^2 (men: 24.3±3.01 kg/m^2, women: 24.2±3.31kg/m^2) , mean WC of 84.0±8.88 cm (men: 85.8±8.89cm, women 82.4±8.57cm), mean HC of 95.3±9.35cm (men: 96.5±9.27cm, women:94.2±9.29cm), mean WHR of 0.883±0.061 (men: 0.891±0.061, women: 0.876±0.061), and mean WHtR of 0.515±0.056 (men: 0.509±0.053,women: 0.520±0.057). Compared with women, men had significantly higher SBP, DBP, and were more likely to be smokers, drinkers, and physically inactive (all $p < 0.05$).

Associations between markers of general and central adiposity with SBP are shown in Figure 1. Compared to central adiposity measures, BMI was the most significant predictor of SBP after considering age, smoking, drinking, physical activity and anthropometric variable. That is, one SD increase in BMI was corresponding to an increase of SBP by about 4.0 mmHg. The next strongest association after adjusting covariates was the HtaW of general adiposity, with each one SD increase associated with about a 3.8 mm Hg higher SBP. The associations for other measures of adiposity were less significant. Similar relationships were observed between different measures of obesity and DBP.

Figure 2 shows the relation of SBP with different anthropometric indices of adiposity separately for men and women. For males, WC was the most strongly related to SBP after adjusting for age, smoking, drinking, physical activity and anthropometric variable, in which 1 SD higher WC (8.89 cm) was associated with an increase in SBP by 3.88 mmHg. For females, BMI was the strongest association with SBP. After adjusting for covariate variables, a one SD higher BMI was associated with a 4.41 mmHg higher SBP. HtaW, HC, WHR, and WHtR had a relatively weaker association with SBP in both males and females. The main findings for SBP were also broadly applicable for DBP.

To verify the gender differences in adiposity and BP in our study, an analysis among men and women in urban and rural areas was performed. Figure 3 and Figure 4 show the associations between SBP and general or central adiposity among males and females in urban and rural areas. For males in both urban and rural areas, WC was the strongest predictor of SBP, with each 1 SD higher WC associated with about a 3.79-mm Hg and a 3.85-mm Hg higher SBP, respectively. In contrast, compared to central adiposity markers, BMI was observed to have the strongest association with SBP among females in both urban and rural areas, with an increase of 1 SD corresponding to an increase of about 4.41 mmHg and 4.47 mmHg SBP, respectively. Among males and females in both areas, the association between HtaW, HC, WHR, WHtR, and BP was less significant for BMI and WC after adjusting for covariate variables. Similar findings were observed for DBP.

Discussion

In the present study, data from a nationally representative study of 135,825 Chinese adults was utilized to examine the relationship between different measures of adiposity and BP. Compared with measures of central adiposity, BMI was observed to be closely associated with BP, with significant gender differences inherent in this association. Specifically, central adiposity measurement such as WC in males and general adiposity parameter such as BMI in females had the strongest associations with SBP/DBP. On average, every 3.18kg/m^2 higher BMI was associated with about 4.04 mm Hg higher SBP and 2.51 mmHg higher DBP. For other markers of adiposity, including HtaW, HC, WHtR and WHR were relatively poor predictors of SBP/DBP in this Chinese adult population. We believe that these findings may also applicable to other Asian countries.

In this study, WC showed the strongest association with BP in males, and BMI showed the strongest association with BP in females, which are in line with findings from some previous studies [15, 23-24]. It was also consistent with the statement from the AHA in 2015, that suggested using WC for evaluating the risk of cardiovascular disease [17]. However, our findings differ from several other studies that reported BMI in men and WC in women having the strongest associations with BP [25-27]. The difference may be explained by the differences in the criteria for evaluating obesity by BMI between Chinese and other populations. It was claimed that the average BMI of Chinese adults with metabolic abnormalities was lower than the WHO's current overweight cut-off point 25kg/m^2, so that an overweight cut-off point of 24kg/m^2 for Chinese has been suggested by WHO [16]. Therefore, the relationship between obesity and BP in Chinese could be different from that in other populations. Another explanation is that use of a lager sample, as in the current study, rather than a small population sample, may also underlie discrepant results.

The strength of associations of BP with BMI was stronger in this Chinese population compared with that previously reported in Western populations [14]. It is well known that there are considerable differences in body fat distribution by ethnicity. Compared with Europeans, Asians tend to have more generalized adiposity [24]. Generalized adiposity is associated with higher BP and other metabolic risk factors [28]. Thus, different body fat distribution may partly account for these between-population differences. Relatively weak associations found in the Western populations might be the result of antihypertensive treatment that is common in western countries, even though such information was not reported in any studies [29]. Furthermore, compared with Western populations, dietary sodium intake is higher in adults in China [30], whereas sodium intake predicts SBP independently of BMI [31], and variation in sodium intake could also explain the differences between these populations.

Interestingly, there are significant gender differences for the relationship between different measures of adiposity and BP. WC, an indicator of central adiposity, showed the strongest association with BP in males, and BMI, a measure of general obesity, showed the strongest association with BP in females. The potential reasons for these gender-specific differences are uncertain, although it may be partly explained by the gender difference in body fat distribution. Visceral fat is predominant in men, and subcutaneous fat is predominant in women [32]. Visceral fat is more likely to result in metabolic abnormalities than subcutaneous fat [33]. In addition, visceral adiposity has the positive correlation with BP [34]. In Asian men with less subcutaneous fat, WC are more appropriate than BMI to indicate visceral fat. Besides, in Asian women with more subcutaneous fat, BMI may be more suitable than waist circumference to indicate total and abdominal fat accumulation [15]. Additionally, compared with females, daily work stress and economic pressure may stimulate males to produce more stress hormones and adrenaline, resulting in more fat into the abdomen [23]. Because WC is a better indicator of abdominal fat [35], it was more strongly associated with BP in males. Further population and laboratory researches are clearly warranted to study the different biological mechanisms between obesity and BP in both males and females.

Proposed mechanisms behind the association of adiposity with BP are complex. Sympathetic nervous system (SNS) up-regulation has been an important mechanism of obesity-related blood pressure. Adipose tissue, especially perivascular adipose tissue, yield leptin, effects on the hypothalamic neuronal systems include reduced food consumption and upregulated thermogenesis and energy expenditure, and stimulation of sympathetic activity. Obesity increases plasma renin and angiotensinogen, which activates the renin - Angiotensin System (RAS). RAS could also make the SNS upregulating [36-37].

Strengths and limitations

The present study has several strengths. Firstly, to the best of our knowledge, this is the first study with a national sample of Chinese adults to compare the relationship between different measures of adiposity with BP. Secondly, this analysis included nearly 140000 adults in China, with adequate statistical power to compare different obesity measures. Limitations of this study were that this was a cross-sectional design, and we cannot infer causality from these results. In addition, all study participants were aged 40 or older, thus results may not be generalizable to younger populations, although similar results have been observed in younger subjects [14, 23].

Conclusion

General obesity is more closely associated with BP than central adiposity, and that gender differences exist in these relationships. Based on the evidence from the present study and the statement of the AHA in 2015, we suggest that in addition to BMI, WC, an index that takes 1-2 minutes to measure, should be added for the general heath checkups for Chinese populations. Further prospective population-based studies and mechanistic studies are still needed to validate our findings.

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Authors' contributions

WNF and ZXL conceived and designed the study. LDW is in charge of this project. SYC, BL, FJS, YG, WZL, SJY, WC, XJW and HL participated in the acquisition of data. WNF and SYC analyzed the data. BL and YG gave advice on methodology. WNF drafted the manuscript, and YG, WNF, BL and ZXL revised the manuscript. All authors read and approved the final manuscript. ZXL is the guarantor of this work and had full access to all the data in the study and take responsibility for its integrity and the accuracy of the data analysis.

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Table1 Baseline characteristics of the study subjects stratified by genders

Variables	**Total(n=135825)**	**Males(n=62451)**	**Females(n=73374)**	***P***
Age groups, n (%)				＜0.01
40-49	42535 (31.3)	19943 (31.9)	22592 (30.8)	
50-59	40226 (29.6)	18014 (28.8)	22212 (30.3)	
60-69	33473 (24.60	15259 (24.4)	18214 (24.8)	
≥70	19591 (14.4)	9235 (14.8)	10356 (14.1)	
Height (cm)	163±8.0	169±6.3	159±6.2	
Weight（kg）	64.7±10.3	69.2±9.9	60.9±9.0	＜0.01
BMI（kg/m^2）	24.3±3.18	24.3±3.01	24.2±3.31	＜0.01
WC (cm)	84.0±8.88	85.8±8.89	82.4±8.57	＜0.01
HC (cm)	95.3±9.35	96.5±9.27	94.2±9.29	＜0.01
WHR	0.883±0.061	0.891±0.061	0.876±0.061	＜0.01
WHtR	0.515±0.056	0.509±0.053	0.520±0.057	＜0.01
SBP (mmHg)	129±16	130±12	129±17	＜0.01
DBP (mmHg)	80±10	81±10	79±10	＜0.01
Smoking n (%)				＜0.01
Yes	22830 (16.8)	20560 (32.9)	2270 (9.9)	
No	112995 (83.2)	41891 (67.1)	71104 (96.9)	
Drinking status n (%)				＜0.01
Yes	19287 (14.2)	18110 (29)	2127 (2.7)	
No	116538 (85.7)	44341 (71)	71247 (97)	
Physical activity n (%)				
Yes	33394 (24.6)	14916 (23.9)	18478 (25.2)	＜0.01
No	102431 (75.5)	47535 (76.1)	54896 (74.8)	

Categorical data were described as percentages and continuous data were described as means ± SD.

BMI: body mass index; HtaW: height-adjusted weight; WC: waist circumference; HC: hip circumference;

WHR: waist-hip ratio; WHtR: Waist-height ratio; SBP: systolic blood pressure; DBP: diastolic blood pressure.

Figure legends

Figure 1 Association between markers of adiposity and systolic blood pressure

95% CI = 95% confidence interval. Adjust for age, smoking, drinking and physical activity.

Figure 2 Association between markers of adiposity and systolic blood pressure in both men and women

95% CI = 95% confidence interval. Adjust for age, smoking, drinking and physical activity.

Figure 3 Association between markers of adiposity and systolic blood pressure in urban areas

95% CI = 95% confidence interval. Adjust for age, smoking, drinking and physical activity.

Figure 4 Association between markers of adiposity and systolic blood pressure in rural areas

95% CI = 95% confidence interval. Adjust for age, smoking, drinking and physical activity.