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Association between obesity indices and blood pressure or hypertension: which index is the best?

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Abstract

Background: The association between obesity and blood pressure is well documented and a series of obesity indices are used as risk factors or indicators of blood pressure and/or the presence of hypertension.

Objective: The aim of the present study was to explore and determine which obesity index is the best indicator of blood pressure and the presence of hypertension among five frequently used simple anthropometric indices.

Methods: Subjects (*n* 29 079) were selected by cluster sampling from fourteen Chinese general populations. Weight, height, waist circumference (WC), hip circumference and blood pressure were measured for each participant. BMI, waist:hip ratio (WHR), waist:stature ratio (WSR) and conicity index (CI) were calculated. Pearson correlation, multiple logistic regression, multivariate linear regression and receiver-operating characteristic (ROC) curve analyses were used.

Results: A total of 13 558 men and 15 521 women were investigated. All five obesity indices were positively correlated with blood pressures and hypertension. After adjusting for age, WSR in men and BMI in women had the greatest association with the presence of hypertension, irrespective of the statistical method used. BMI had the strongest correlation with continuous blood pressures in both genders.

Conclusion: The present results indicate that hypertension is associated with different obesity indices in men and in women. The best indicator for hypertension is WSR in men while it is BMI in women.

Keywords
Obesity
Hypertension
Body mass index
Waist:stature ratio
Receiver-operating characteristic curve analysis

Hypertension and obesity are both very important issues in primary care in the 21st century and have become two growing worldwide epidemics[1,2]. Many epidemiological studies have shown a progressive increase in the prevalence of elevated blood pressure or hypertension with increasing obesity[3–9]. A series of anthropometric indices were used as obesity measures in these studies, including BMI, waist:hip ratio (WHR), waist circumference (WC), waist:stature ratio (WSR) and conicity index (CI). However, it is not yet fully clear which anthropometric index of obesity has the strongest association with hypertension.

BMI has been most frequently used in many epidemiological studies as a measure of body fatness[3–11]. Also, several studies have indicated that BMI is highly correlated with overall obesity but relatively poorly with visceral obesity (central obesity, android-type obesity or abdominal adiposity)[12], which tends to be more closely associated with blood pressure and/or hypertension[6–10,13]. Thus there is a need to find other obesity indices better associated with visceral obesity. WC, WHR and WSR were measured and calculated to meet this need, and have been shown to be strongly correlated with prevalent CHD and other associated disorders independent of BMI, or even better than BMI[11]. Another index to measure abdominal adiposity is the CI[14], introduced in 1991 by Valdez, who claimed that CI has several advantages over WHR. Ho *et al.* reported that WSR was more strongly associated with cardiovascular risk factors than other simple anthropometric indices among Hong Kong Chinese adults[15]. Savva *et al.* indicated that WSR and WC were both better associated with CVD risk factors than BMI in children[16]. Although recently there have been several valuable articles focused on the issue of which obesity index is best associated with blood pressure and hypertension[17–21], they were limited by either small sample size or inadequate consideration of obesity measures.

In order to explore and compare the association between different obesity indices and blood pressure and presence of hypertension, we used the data from a large, population-based epidemiological study[22] and chose five different anthropometric indices as obesity measures: BMI, WSR, WC, WHR and CI. The reasons for choosing these five indices were: (i) they are easily obtained without

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expensive or complex instruments; (ii) they are conveniently self-measurable; and (iii) they have been frequently used in many previous epidemiological studies.

Subjects and methods

Fourteen centres based on fourteen populations from thirteen provinces across China were established, which were able to represent the average standards of living, education and health care in mainland China. Based on data from the local household registration system in each cohort, subjects were selected by cluster random sampling from each established population. There was no significant heterogeneity across these sites. Each participating centre was responsible for 2000 to 2500 subjects (born in or before 1972) and the ratio of male participants to female was required to be 1:1. Selected subjects were asked from their homes to come to the appointed place for examinations and interviews. Approval for all protocols of the present study was obtained from the review board of the Health Ministry of the People's Republic of China. A regular hospital or health agency in each area was appointed to provide equipment and venues for the study to perform examinations and interviews. All participants received a detailed introduction to the study by local government and medical organizations, which included appointed hospitals, centres for disease control and prevention, and the health departments in local governments. The informed consent was obtained from participants by local medical organizations. All examinations for participants were free and no participant was paid.

Anthropometry

The researchers (including physicians as interviewers and technicians as assistants) from each participating centre were gathered and received unified training before the survey started, in order that the same standards of measurements were used across the centres.

Weight was measured with a pointer spring balance to the nearest 0·1 kg. Height was measured to the nearest 1 cm using a non-stretchable tape measure. WC was measured at the midpoint between the bottom of the ribs and the top of the iliac crest. Hip circumference was measured at the largest posterior extension of the buttocks. Both WC and hip circumference were measured to the nearest 1 cm with an inelastic tape. All anthropometric measures were taken in the fasting state, with the participants dressed in light clothing and without shoes. Every morning, the spring balance was calibrated with a standard weight. BMI, WSR and WHR were calculated using the following formulas:

$$\text{BMI} = \frac{\text{weight (kg)}}{\text{height}^2\,(\text{m}^2)},$$

$$\text{WSR} = \frac{\text{WC (cm)}}{\text{height (cm)}}$$

and

$$\text{WHR} = \frac{\text{WC (cm)}}{\text{hip circumference (cm)}}.$$

CI was determined through the measurements of weight, height and WC, using the following formula[14]:

$$\text{CI} = \frac{\text{WC (m)}}{0{\cdot}109 \times \sqrt{\text{weight (kg)}/\text{height (m)}}}.$$

Blood pressure measurements

Each participant's blood pressure was measured in the right arm at sitting position using a standardized mercury column sphygmomanometer with a standardized protocol[23]. The participants rested for at least 10 min in seated position before the measurements, with their arm supported at the level of the heart. All subjects wore light clothing (no tight clothing constricting the arm) and were in optimal room conditions. Smokers were required to stop smoking for at least 15 min before blood pressure was measured. No stimulant drink, such as tea, coffee or alcohol, was allowed within 30 min before blood pressure was taken. Each participant's blood pressure was measured three times with a 2 min interval between measurements. The mean of the three readings was accepted as the final value. Systolic blood pressure (SBP) was accepted as the first Korotkoff sound phase and diastolic blood pressure (DBP) as the fifth phase (disappearance of sounds) to the nearest 2 mmHg. Three different cuff sizes were used on the participants according to their arm circumference (small adult = 12 cm × 23 cm for <25 cm; standard adult = 15 cm × 30 cm for 25–35 cm; large adult = 18 cm × 36 cm for >35 cm) as per the recommendations of the Chinese Hypertension League[24]. Cases of hypertension were defined as SBP ≥ 140 mmHg or DBP ≥ 90 mmHg or use of blood pressure-lowering drugs.

Data collection

Each participant was required to respond to an interviewer-led questionnaire especially designed for the survey. The questionnaires were all recorded by the trained interviewers based on face-to-face interviews. The interviewers obtained demographic details, recorded the family medical history and education level, and inquired about smoking and alcohol drinking habits. Medical history of diabetes, hypertension, dyslipidaemia and hyperthyroidism was self-reported. Participants did not take blood tests for blood sugar, blood lipids or thyroid function. Participants were categorized as smokers if they were current smokers or former smokers and as non-smokers if they never smoked; and categorized as users (current or former) or non-users (never) regarding their alcohol usage.

Statistical analysis

Statistical analyses were performed mostly using the SPSS for Windows statistical software package version 15·0

(SPSS Inc., Chicago, IL, USA). Descriptive statistics for obesity indices were calculated for both men and women. Differences in continuous variables between genders were tested with Student's *t* test, including age, SBP, DBP, WC, BMI, WSR, WHR and CI. Differences in binomial categorized variables between men and women were analysed with Pearson's χ^2 test, including hyperthyroidism (yes/no), educated (yes/no), smoking (yes/no), hypertension (yes/no), drinking (yes/no), diabetes (yes/no), dyslipidaemia (yes/no), SBP ≥ 140 mmHg (yes/no) and DBP ≥ 90 mmHg (yes/no). Correlation coefficients between WC, BMI, WSR, WHR and CI were calculated by Pearson correlation analyses.

Because anthropometric indices (continuous) are highly correlated with each other, they were tested separately in multiple backward stepwise logistic regression models after adjusting for age (continuous), hyperthyroidism, education, smoking, hypertension, drinking, diabetes and dyslipidaemia. Due to high multicollinearity, they were not considered as independent variables in the same regression model with hypertension (yes/no) as the dependent variable. Obesity indices were then categorized as quadrinomial variables using their quartiles as cut-off points and tested separately again in multiple backward stepwise logistic regression models using the first quartile as reference category. After categorization, obesity measures were also put into the same regression models to test their independent relationship with the presence of hypertension, because multicollinearity between categorized indices was thought to be not as strong as that between continuous indices.

Multivariate linear stepwise regression was performed to analyse the association of each obesity index with SBP (continuous) or DBP (continuous) as dependent variable, respectively, after adjustment for age (continuous), hyperthyroidism, education, smoking, hypertension, drinking, diabetes and dyslipidaemia. Again, anthropometric indices for obesity were not tested together in a same regression model due to high multicollinearity.

Receiver-operating characteristic (ROC) curve analysis was performed with the Medcalc program version 9·3·9·0 (MedCalc Software, Mariakerke, Belgium). The ROC curve is a plot of the sensitivity *v.* 1–specificity for each cut-off value.

Area under the curve (AUC) was calculated both directly and after adjustment for age. The AUC is an indicator of how well the anthropometric indices for obesity can distinguish the presence of hypertension, elevated SBP or elevated DBP. Results from ROC curve analysis could be used for inter-verification with those from the multivariate regression model. Pairwise comparisons between AUC were performed using the *Z* test. SBP and DBP were categorized into binomial variables by the cut-off value of 140 mmHg and 90 mmHg, respectively. When ROC curve analyses for DBP and SBP were performed, 4905 cases taking antihypertensive medicine were excluded because their blood pressure may not reflect the real value. Exact confidence intervals were calculated by StatPages.net (http://statpages.org/confint.html) based on binomial distribution. All *P* values reported are two-tailed and $P < 0·05$ was considered to be statistically significant.

Results

The present cross-sectional study investigated 29 079 subjects (mean age 52·5 (SD 22·4) years, range 30–100 years), including 13 558 men and 15 521 women. The response rate was about 96 %. The most common reason for non-participation (4 %) was due to refusal of examination. Male subjects were significantly older than female subjects (53·3 (SD 11·6) years *v.* 51·9 (SD 11·3) years, $P < 0·001$). The anthropometric obesity indices, demographic characteristics and disease variables of the study population are shown in Table 1.

The correlations between obesity indices were all very strong ($r > \sim 0·70$; see Table 2), except for correlations of BMI with WHR ($r = 0·331$, $P < 0·001$ among women; $r = 0·442$, $P < 0·001$ among men) and BMI with CI ($r = 0·236$, $P < 0·001$ among women; $r = 0·227$, $P < 0·001$ among men).

Multiple backward stepwise logistic regression analyses were performed using WC, BMI, WSR, CI and WHR as the independent variable, respectively, and hypertension (yes/no) as the dependent variable to test the association between each obesity measure and hypertension. The results are shown in Table 3 as odds ratios not adjusted, adjusted only for age, and adjusted for age, smoking, education, drinking, hyperthyroidism, dyslipidaemia and diabetes. Whether with adjustment or without, the order of OR for obesity indices regarding the presence of hypertension was WSR (per 0·01) > WHR (per 0·01) > WC (per 1 cm) > CI (per 0·01) > BMI (per 0·1 kg/m^2) in men and WSR (per 0·01) > WC (per 1 cm) > WHR (per 0·01) > CI (per 0·01) > BMI (per 0·1 kg/m^2) in women. However, if the measurement unit of BMI was set to 1 kg/m^2 instead of 0·1 kg/m^2, the OR for BMI increased markedly and became the largest one.

Next, the five obesity indices were transformed into quadrinomial categorized variables using their quartiles as cut-off points and entered logistic regression analyses again using the first quartile as reference value. The results are given in Table 4. Without adjustment, the orders were WSR > WC > CI > BMI > WHR in men and WSR > WC > BMI > CI > WHR in women. After adjusting for age only or age and other factors, the order became WSR > WC > BMI > CI > WHR in men and BMI > WSR > WC > WHR > CI in women. Similar trends to the above results would be found if the five obesity indices (as quartiles) were entered into the same logistic regression model (detailed tables not shown).

Table 1 The anthropometric indices, demographic characteristics and prevalence of diseases in men and women: subjects (*n* 29 079) from fourteen Chinese general populations, mainland China

	Men (*n* 13 558)		Women (*n* 15 521)		
	Prevalence or proportion (%)	95 % confidence interval	Prevalence or proportion (%)	95 % confidence interval	*P* value
Hyperthyroidism	0·53	0·42, 0·67	1·88	1·67, 2·11	<0·001
Educated†	38·9	38·08, 39·73	29·88	29·16, 30·01	<0·001
Smoking	68·84	68·06, 69·62	6·81	6·42, 7·22	<0·001
Hypertension	36·96	36·15, 37·78	34·95	34·20, 35·70	<0·001
Drinking	63·86	63·04, 64·68	10·75	10·26, 11·24	<0·001
Diabetes	3·31	3·05, 3·67	3·70	3·41, 4·01	0·069
Dyslipidaemia	11·34	10·81, 11·89	11·50	11·00, 12·01	0·675
SBP (≥140 mmHg)	25·37	24·64, 26·11	25·82	25·13, 26·51	0·387
DBP (≥90 mmHg)	19·57	18·90, 20·25	13·83	13·29, 14·39	<0·001
	Mean	SD	Mean	SD	
Age (years)	53·3	11·6	51·9	11·3	<0·001
SBP (mmHg)	129·5	19·2	127·4	21·8	<0·001
DBP (mmHg)	80·5	11·3	77·4	11·2	<0·001
Hip circumference (cm)	95·5	8·8	96·8	8·9	<0·001
Height (cm)	167·53	6·98	156·05	6·75	<0·001
Weight (kg)	68·48	10·98	59·64	9·79	<0·001
WC (cm)	84·7	9·8	80·9	10·2	<0·001
BMI (kg/m^2)	24·33	3·20	24·45	3·55	0·002
WSR	0·506	0·058	0·519	0·066	<0·001
WHR	0·877	0·063	0·835	0·066	<0·001
CI	1·219	0·096	1·204	0·105	<0·001

SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio; CI, conicity index.
†Educated = high school attainment or further.

Table 2 Pearson correlation coefficients between anthropometric obesity indices among subjects (*n* 29 079) from fourteen Chinese general populations, mainland China

		WC	BMI	WSR	WHR	CI
Women	WC	–	0·740	0·948	0·669	0·809
	BMI	0·740	–	0·729	0·331	0·236
	WSR	0·948	0·729	–	0·683	0·817
	WHR	0·669	0·331	0·683	–	0·731
Men	WC	–	0·746	0·938	0·713	0·797
	BMI	0·746	–	0·719	0·442	0·227
	WSR	0·938	0·719	–	0·726	0·817
	WHR	0·713	0·442	0·726	–	0·693

WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio; CI, conicity index.
Each coefficient was statistically significant: $P < 0·001$.

Table 5 presents the correlation coefficients of obesity measures with blood pressure. Multivariate linear stepwise regression analysis was used with SBP and DBP as the continuous dependent variable, respectively. Before this analysis, we excluded 4905 subjects with hypertension who took antihypertensive medicine regularly or irregularly. Both in men and in women, the orders of correlation with SBP and DBP were BMI > WC > WSR > WHR > CI. In men BMI was positively correlated with ($\beta = 0·264$) and explained 18·7 % of the variance in SBP, followed by WC (17·2 %) and WHR (14·2 %), while both CI (13·3 %) and WSR (13·2 %) explained a similar amount of variance; BMI was also most correlated with DBP in men ($\beta = 0·323$) and explained more variance (12·0 %) than any other obesity index. In women, the order of amount of SBP variance explained was BMI > WSR > WC > WHR > CI, where BMI ($\beta = 0·265$) explained 26·3 % of the variance in SBP; and the order for DBP was BMI > WC > WSR > WHR > CI, where BMI ($\beta = 0·311$) explained 11·5 % of the variance in DBP. All obesity measures were significantly ($P < 0·001$) and positively associated with blood pressure.

AUC in men and women are listed in Table 6 and the *P* values of pairwise comparisons are listed in Table 7. ROC analyses for associations between the five indices and hypertension are shown in Fig. 1 for men and Fig. 2 for women.

In men, ROC curve analyses showed that AUC of WSR for hypertension was always the largest among the five anthropometric indices whether adjusted for age or not. However, pairwise comparison indicated that the difference between AUC of WSR and WC for hypertension was not statistically significant (0·737 *v.* 0·735, $P = 0·066$). When SBP was used as the classification variable with cut-off point ≥140 mmHg or DBP was used with cut-off point ≥90 mmHg, WSR had the largest AUC for SBP and DBP without adjustment for age. After adjusting for age, however, AUC of WSR was slightly lower than that of WC for DBP (0·668 *v.* 0·670, $P = 0·594$) and slightly higher than AUC of BMI (0·665, $P = 0·545$), both differences being statistically insignificant. AUC of WSR for hypertension and SBP were still significantly higher than the AUC of any other index after adjustment for age.

Table 3 Crude and adjusted odds ratios for hypertension according to different obesity measures among subjects (*n* 29 079) from fourteen Chinese general populations, mainland China

	Crude		Adjusted†		Adjusted‡	
	OR	95 % confidence interval	OR	95 % confidence interval	OR	95 % confidence interval
Men						
WC (per 1 cm)	1·067	1·063, 1·072	1·068	1·063, 1·072	1·054	1·050, 1·059
BMI (per 0·1 kg/m^2)	1·016	1·015, 1·018	1·019	1·018, 1·020	1·018	1·017, 1·019
WSR (per 0·01)	1·134	1·126, 1·142	1·123	1·115, 1·131	1·112	1·104, 1·120
WHR (per 0·01)	1·070	1·064, 1·077	1·069	1·062, 1·075	1·062	1·055, 1·069
CI (per 0·01)	1·058	1·053, 1·062	1·045	1·041, 1·050	1·040	1·036, 1·045
BMI (per 1 kg/m^2)	1·178	1·164, 1·192	1·214	1·198, 1·229	1·195	1·180, 1·211
Women						
WC (per 1 cm)	1·076	1·072, 1·080	1·060	1·055, 1·064	1·062	1·057, 1·066
BMI (per 0·1 kg/m^2)	1·019	1·018, 1·020	1·019	1·018, 1·020	1·018	1·016, 1·019
WSR (per 0·01)	1·131	1·124, 1·138	1·092	1·086, 1·099	1·084	1·077, 1·091
WHR (per 0·01)	1·067	1·061, 1·073	1·037	1·031, 1·043	1·033	1·027, 1·039
CI (per 0·01)	1·055	1·051, 1·059	1·023	1·019, 1·027	1·019	1·015, 1·023
BMI (per 1 kg/m^2)	1·205	1·193, 1·218	1·204	1·191, 1·217	1·190	1·176, 1·203

WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio; CI, conicity index.
Each OR was statistically significant: $P < 0{\cdot}001$.
†Adjusted for age.
‡Adjusted for age, smoking, education, drinking, hyperthyroidism, dyslipidaemia and diabetes.

In women, if not adjusted for age, AUC of WSR was still larger than that of any other index, while after adjustment for age BMI had the largest AUC for all three classification variables and the differences were all statistically significant.

Discussion

As early as 1967, data from the Framingham Study indicated that obesity is a leading risk factor for chronic arterial hypertension[25]. Several previous studies have tried to find which anthropometric index correlates most closely with blood pressure and incidence or prevalence of hypertension, when used to define obesity. Mark *et al.* found that the prevalence of elevated blood pressure was positively correlated with increasing adipose tissue[17]. Fuchs *et al.* reported that WC was a very important screening tool for elevated blood pressure in a cross-sectional study, though still less important than BMI[19]. Also, a longitudinal study with relatively small sample reported by Fuchs *et al.* indicated that the correction of waist by stature or hip circumference improved its prediction of the incidence of hypertension, even better than that for BMI[19]. However, these studies involved fewer obesity measures than the present study and were not able to fully solve the question.

Only two previous studies explored the association of all five simple anthropometric obesity indices with blood pressure and hypertension[20,21]. The most recent one was conducted in Singapore, in which Ghosh and Bandyopadhyay claimed that BMI, WSR and WC had stronger correlations than other anthropometric indices with both SBP and DBP as continuous variables[21]. Similar trends could be seen in the present study. Ghosh and Bandyopadhyay tried to compare the relationship of obesity measures with the presence of hypertension using multiple logistic regression models and found that BMI was associated with greater risk of hypertension. As seen in our results (Table 3), however, the OR for obesity measures highly depends on the size of the measurement unit when the logistic regression model is used. BMI's association with hypertension became the weakest among obesity indices if its measurement unit was set to 0·1 kg/m^2 and the strongest with 1 kg/m^2 per measurement. That is, the OR for a continuous variable increases with the size of measurement unit in the logistic regression analysis. Therefore, without a standard measurement unit for each obesity index being clearly and reasonably defined, direct comparison between obesity measures based on OR value becomes invalid or at least less convincing. In the present study, besides the method used in Table 3, we transformed each obesity measure into a categorical variable by its quartiles to avoid the issue related to the measurement unit and then made a comparison using a logistic regression model. Thus we found that WSR rather than BMI was the best indicator for hypertension in men and BMI was best associated with hypertension in women after adjusting for age and/or other risk factors. Moreover, this result was in agreement with that from ROC curve analysis.

Results from three studies which investigated the same five obesity measures are listed in Table 8; they include the study from Cambridge by Yalcin *et al.*[18], Ghosh and Bandyopadhyay[21] and the present study. In spite of the obviously small sample size of the two previous studies, all three studies indicated BMI, WSR and WC to have stronger correlations with both SBP and DBP in both genders. In fact, compared with the two previous studies, the order of correlation between obesity measures and

Table 4 Crude and adjusted odds ratios for hypertension according to different obesity measures in quartiles among subjects (*n* 29 079) from fourteen Chinese general populations, mainland China

	Men							Women						
		Crude		Adjusted†		Adjusted‡			Crude		Adjusted†		Adjusted‡	
	Quartile	OR	95 % confidence interval	OR	95 % confidence interval	OR	95 % confidence interval	Quartile	OR	95 % confidence interval	OR	95 % confidence interval	OR	95 % confidence interval
WC	<78	1·000	–	1·000	–	1·000	–	<74	1·000	–	1·000	–	1·000	–
	78–<84	1·262	1·125, 1·415	1·332	1·182, 1·500	1·276	1·132, 1·438	74–<80	1·634	1·455, 1·835	1·481	1·309, 1·675	1·413	1·248, 1·599
	84–<91	2·141	1·921, 2·386	2·299	2·054, 2·574	2·134	1·904, 2·392	80–<87	2·724	2·447, 3·033	2·231	1·991, 2·500	2·087	1·860, 2·341
	≥91	4·632	4·160, 5·158	4·792	4·283, 5·361	4·179	3·727, 4·686	≥87	6·434	5·789, 7·151	4·491	4·014, 5·025	3·953	3·527, 4·430
BMI	<22·14	1·000	–	1·000	–	1·000	–	<21·91	1·000	–	1·000	–	1·000	–
	22·14–<24·27	1·322	1·187, 1·471	1·556	1·389, 1·742	1·487	1·327, 1·667	21·91–<24·17	1·651	1·484, 1·838	1·775	1·580, 1·994	1·688	1·501, 1·897
	24·27–<26·40	1·934	1·743, 2·147	2·375	2·126, 2·654	2·178	1·946, 2·437	24·17–26·64	2·620	2·362, 2·906	2·774	2·478, 3·105	2·605	2·325, 2·918
	≥26·40	3·607	3·253, 4·000	4·618	4·134, 5·159	4·067	3·634, 4·552	≥26·64	5·325	4·807, 5·900	5·368	4·802, 6·002	4·779	4·269, 5·350
WSR	<0·463	1·000	–	1·000	–	1·000	–	<0·473	1·000	–	1·000	–	1·000	–
	0·463–<0·506	1·692	1·511, 1·896	1·679	1·494, 1·887	1·615	1·436, 1·816	0·473–<0·515	1·915	1·710, 2·144	1·566	1·392, 1·763	1·490	1·323, 1·679
	0·506–<0·545	2·959	2·651, 3·302	2·822	2·521, 3·160	2·569	2·291, 2·880	0·515–<0·561	3·473	3·116, 3·871	2·437	2·175, 2·731	2·244	2·000, 2·518
	≥0·545	6·041	5·414, 6·741	5·317	4·750, 5·952	4·643	4·139, 5·207	≥0·561	8·008	7·187, 8·922	4·532	4·039, 5·084	3·954	3·517, 4·446
WHR	<0·835	1·000	–	1·000	–	1·000	–	<0·794	1·000	–	1·000	–	1·000	–
	0·835–<0·876	1·398	1·257, 1·556	1·423	1·274, 1·590	1·360	1·215, 1·522	0·794–<0·833	1·689	1·525, 1·870	1·444	1·296, 1·610	1·353	1·211, 1·510
	0·876–<0·917	2·134	1·924, 2·368	2·138	1·919, 2·382	1·968	1·763, 2·195	0·833–<0·873	2·088	1·888, 2·308	1·603	1·440, 1·785	1·480	1·327, 1·651
	≥0·917	3·084	2·782, 3·418	3·074	2·762, 3·421	2·771	2·485, 3·089	≥0·873	3·393	3·073, 3·746	2·155	1·937, 2·399	1·958	1·756, 2·183
CI	<1·157	1·000	–	1·000	–	1·000	–	<1·141	1·000	–	1·000	–	1·000	–
	1·221–<1·157	1·853	1·661, 2·068	1·748	1·562, 1·956	1·668	1·488, 1·868	1·141–<1·201	1·693	1·523, 1·881	1·303	1·165, 1·456	1·231	1·100, 1·379
	1·201–<1·279	2·664	2·392, 2·966	2·354	2·108, 2·629	2·137	1·910, 2·390	1·201–<1·141	2·694	2·432, 2·984	1·696	1·520, 1·893	1·542	1·380, 1·724
	≥1·279	4·244	3·814, 4·723	3·288	2·944, 3·673	2·933	2·621, 3·283	≥1·265	4·536	4·098, 5·021	2·165	1·936, 2·421	1·916	1·710, 2·148

WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio; CI, conicity index.
Each OR was statistically significant: $P < 0·001$.
†Adjusted for age.
‡Adjusted for age, smoking, education, drinking, hyperthyroidism, dyslipidaemia and diabetes.

Table 5 Multivariate linear stepwise regression analysis of obesity measures with blood pressure among subjects (*n* 24 174) from fourteen Chinese general populations, mainland China

	SBP			DBP		
	β	R^2	P	β	R^2	P
Men						
BMI	0·264	0·187	*	0·323	0·12	*
WC	0·236	0·172	*	0·291	0·101	*
WSR	0·212	0·132	*	0·269	0·088	*
WHR	0·15	0·142	*	0·176	0·051	*
CI	0·118	0·133	*	0·133	0·037	*
Women						
BMI	0·265	0·263	*	0·311	0·115	*
WC	0·227	0·221	*	0·267	0·085	*
WSR	0·226	0·237	*	0·241	0·071	*
WHR	0·109	0·206	*	0·114	0·034	*
CI	0·082	0·201	*	0·083	0·028	*
Both						
BMI	0·254	0·193	*	0·304	0·11	*
WC	0·225	0·178	*	0·281	0·093	*
WSR	0·212	0·172	*	0·232	0·068	*
WHR	0·14	0·148	*	0·165	0·044	*
CI	0·096	0·139	*	0·106	0·029	*

SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio; CI, conicity index.
$^*P < 0·001$.

hypertension in our study is more consistent between different groups, which may be due to three reasons: (i) the sample size in the present study was large; and/or (ii) in order to avoid multicollinearity from which Yalcin's study suffered[18], all five obesity indices in the present study were tested in multivariate linear stepwise regression models separately adjusted for other factors. On the other hand, (iii) considering the small sample size and potential problem in statistics in the two previous studies, conclusions made in the present study should be more reliable, although results in the mentioned two studies are in agreement with each other in men (see Table 8). However, it should be noted that results from both ROC curve and logistic regression analyses in the present study showed that the 'strongest' obesity measure for hypertension in men is WSR rather than BMI. In our analysis with the linear stepwise regression model, 4905 patients with hypertension were excluded in order to get rid of the confounding effects of antihypertensive drugs on blood pressure. Excluding these participants who potentially contained information related to hypertension, however, may in turn have compromised the results to some extent. Despite this possibility, results in our study are still convincing due to the large sample size and because they do not suffer from multicollinearity. Furthermore, the obesity measure that most closely correlates with continuous change of blood pressure per 1 mmHg may not have the same strong association with the presence of hypertension. Further data, especially from large-scale prospective studies, are still needed to verify the relationships and the correlation orders.

ROC curves are frequently used to compare the diagnostic performance of two or more laboratory or diagnostic

Table 6 Areas under the receiver-operating characteristic curves (AUC) of obesity indices for hypertension and blood pressure among subjects (*n* 29 079 for hypertension, *n* 24 174 for SBP and DBP) from fourteen Chinese general populations, mainland China

	Hypertension†		SBP†		DBP†		Hypertension‡		SBP‡		DBP‡	
	AUC	95 % confidence interval	AUC	95 % confidence interval	AUC	95 % confidence interval	AUC	95 % confidence interval	AUC	95 % confidence interval	AUC	95 % confidence interval
Men												
BMI	0·730	0·722, 0·737	0·724	0·716, 0·732	0·665	0·657, 0·674	0·642	0·634, 0·650	0·601	0·592, 0·610	0·665	0656, 0·673
CI	0·703	0·695, 0·710	0·702	0·694, 0·710	0·612	0·603, 0·620	0·649	0·640, 0·657	0·625	0·616, 0·633	0·609	0601, 0·618
WC	0·735	0·727, 0·742	0·725	0·717, 0·733	0·670	0·661, 0·678	0·671	0·663, 0·679	0·628	0·619, 0·636	0·670	0662, 0·678
WHR	0·703	0·696, 0·711	0·704	0·695, 0·712	0·626	0·617, 0·634	0·624	0·615, 0·632	0·601	0·592, 0·609	0·626	0617, 0·634
WSR	0·737	0·730, 0·745	0·729	0·721, 0·737	0·668	0·660, 0·677	0·691	0·683, 0·699	0·654	0·646, 0·663	0·680	0672, 0·688
Women												
BMI	0·778	0·772, 0·785	0·768	0·761, 0·775	0·683	0·675, 0·691	0·678	0·671, 0·685	0·647	0·639, 0·655	0·571	0563, 0·580
CI	0·736	0·729, 0·743	0·738	0·730, 0·745	0·569	0·561, 0·577	0·660	0·652, 0·667	0·646	0·638, 0·655	0·655	0647, 0·663
WC	0·769	0·762, 0·776	0·759	0·752, 0·767	0·654	0·646, 0·662	0·697	0·690, 0·705	0·670	0·662, 0·678	0·579	0570, 0·587
WHR	0·736	0·729, 0·743	0·739	0·732, 0·747	0·577	0·569, 0·585	0·625	0·618, 0·633	0·620	0·611, 0·628	0·646	0638, 0·654
WSR	0·766	0·759, 0·772	0·760	0·753, 0·768	0·644	0·636, 0·653	0·714	0·707, 0·721	0·694	0·686, 0·702	0·680	0672, 0·688

SBP, systolic blood pressure; DBP, diastolic blood pressure; CI, conicity index; WC, waist circumference; WHR, waist:hip ratio; WSR, waist:stature ratio.
SBP and DBP were categorized into binomial variables by cut-off value of 140 mmHg and 90 mmHg, respectively.
†Adjusted for age.
‡Not adjusted.

Table 7 *P* values in pairwise comparisons of areas under the receiver-operating characteristic curve between anthropometric obesity indices for different classification variables among subjects (*n* 29 079 for hypertension, *n* 24 174 for SBP and DBP) from fourteen Chinese general populations, mainland China

		Men					Women				
Classification variable		BMI	CI	WC	WHR	WSR	BMI	CI	WC	WHR	WSR
Hypertension†	BMI	–	*	0·066	*	0·005	–	*	*	*	*
	CI	*	–	*	0·814	*	*	–	*	0·705	*
	WC	0·066	*	–	*	0·037	*	*	–	*	0·003
	WHR	*	0·814	*	–	*	*	0·705	*	–	*
SBP†	BMI	–		0·708	*	*	–	*	*	*	0·002
	CI	*	–	*	0·445	*	*	–	*	0·303	*
	WC	0·708	*	–	*	0·008	*	*	–	*	0·338
	WHR	*	0·445	*	–	*	*	0·303	*	–	*
DBP†	BMI	–	*	0·371	*	0·545	–	*	*	*	*
	CI	*	–	*	*	*	*	–	*	0·169	*
	WC	0·371	*	–	0·012	0·594	*	*	–	*	*
	WHR	*	0·012	*	–	*	*	0·169	*	–	*
Hypertension‡	BMI	–	0·322	*	0·001	*	–	0·002	*	*	*
	CI	0·322	–	*	*	*	0·002	–	*	*	*
	WC	*	*	–	*	*	*	*	–	*	*
	WHR	*	0·001	*	–	*	*	*	*	–	*
SBP‡	BMI	–	0·003	*	*	*	–	0·933	*	*	*
	CI	0·003	–	0·482	0·976	*	0·933	–	*	*	*
	WC	*	0·482	–	*	*	*	*	–	*	*
	WHR	0·976	*	*	–	*	*	*	*	–	*
DBP‡	BMI	–	*	0·351	*	0·729	–	*	*	*	*
	CI	*	–	*	0·004	*	*	–	*	0·195	*
	WC	0·351	0	–	*	0·288	*	*	–	*	0·004
	WHR	*	0·004	*	–	*	*	0·195	*	–	*

CI, conicity index; WC, waist circumference; WHR, waist:hip ratio; WSR, waist:stature ratio; SBP, systolic blood pressure; DBP, diastolic blood pressure. SBP and DBP were categorized into binomial variables by cut-off value of 140 mmHg and 90 mmHg, respectively.

$^*P < 0{\cdot}001$.

†Adjusted for age.

‡Not adjusted.

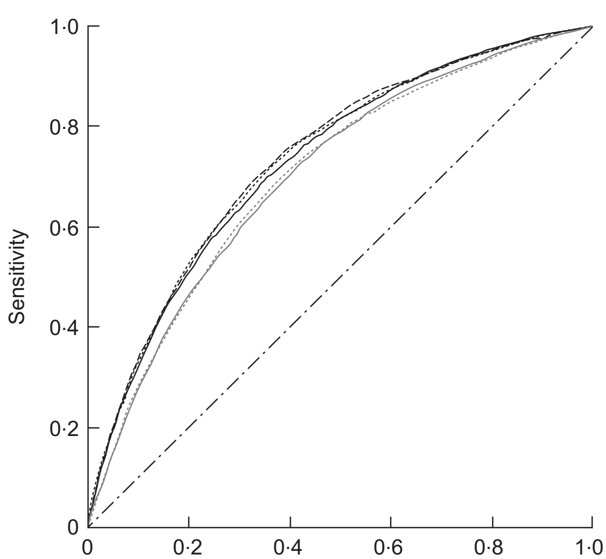

Fig. 1 Receiver-operating characteristic curves of obesity indices (———, BMI; ———, conicity index; ············, waist circumference; ············, waist:hip ratio; – – – – – – –, waist:stature ratio) for hypertension among male subjects (*n* 13 558) from fourteen Chinese general populations, mainland China. —·—·– indicates area under the curve of 0·5 (line indicating no discriminative capability)

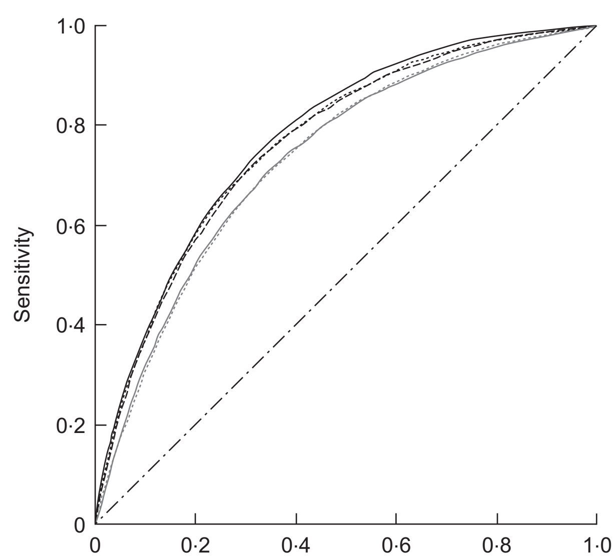

Fig. 2 Receiver-operating characteristic curves of obesity indices (———, BMI; ———, conicity index; ············, waist circumference; ············, waist:hip ratio; – – – – – – –, waist:stature ratio) for hypertension among female subjects (*n* 15 521) from fourteen Chinese general populations, mainland China. —·—·– indicates area under the curve of 0·5 (line indicating no discriminative capability)

Table 8 Comparison of correlation orders of obesity measures with blood pressure

		Present study (*n* 29 079)	Yalcin *et al.*[18] (*n* 267)	Ghosh & Bandyopadhyay[21] (*n* 180)
SBP	Men	BMI > WC > WSR > WHR > CI	WSR > BMI > WC > WHR > CI	WSR > BMI > WC > WHR > CI
	Women	BMI > WC > WSR > WHR > CI	WC > BMI > WSR > CI > WHR	–
DBP	Men	BMI > WC > WSR > WHR > CI	BMI > WC > WSR > WHR > CI	BMI > WC > WSR > WHR > CI
	Women	BMI > WC > WSR > WHR > CI	WC > WSR > CI > WHR > BMI	–

WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio; CI, conicity index; SBP, systolic blood pressure; DBP, diastolic blood pressure.

tests, and were first used by Ho *et al.* in 2003 to select the best index in relation to cardiovascular risks, including hypertension, SBP and DBP[15]. Ho *et al.* reported in their study that WSR was more strongly associated with hypertension, SBP and DBP than other simple anthropometric indices. Unfortunately however, the results were not adjusted for age, which may render the conclusion invalid. As listed in Tables 6 and 7, results in the present study showed in both men and women that the AUC of WSR was significantly the largest for hypertension, SBP and DBP before adjusting for age; but after adjustment for age, AUC of WSR was the largest only in men and second to that of BMI in women.

In the present study, WSR in men and BMI in women had the closest correlation with the presence of hypertension, and these results were very consistent across two logistic regression models (with obesity indices as continuous or categorized variables) and ROC curve analyses. This major difference between the two sexes was never reported before. Many previous studies[6–10,13] indicated that visceral obesity measured by WC or WHR was more closely associated with blood pressure and/or the presence of hypertension than overall obesity measured by BMI; while a study in 1992 claimed that BMI had a better correlation with blood pressure in both men and women[26]. Most of these studies were limited by relatively small sample size and almost all of them suffered from multicollinearity in statistical analysis with either a logistic regression model or a linear stepwise regression model. Moreover, none of them performed important ROC curve analysis to explore the predictive value of these anthropometric indices for hypertension. This may partly explain why they could not reveal the major difference between the genders. One previous study based on a Hong Kong Chinese population[27] reported that types of obesity of men and women were clearly different according to WHR and BMI, but the authors did not perform further analysis between obesity measures and blood pressure as done in our study. Moreover, in our study, all obesity measures as quartiles in the same logistic regression model also supported that WSR and BMI rather than WC had stronger correlation with hypertension. WSR has been proved to be a good indicator of abdominal visceral fat[28] and cardiovascular risk factors[15], while BMI is by far a good indicator for overall adiposity[12]. Consequently, the present results indicate that men's hypertension depends mainly on visceral obesity and women's hypertension correlates mainly with overall adiposity.

Furthermore, the linear regression coefficients for each obesity measure with continuous SBP or DBP were substantially greater in men than in women, suggesting a greater male responsiveness of blood pressure to a gain in relative weight or abdominal deposition. This result is totally different from that in the study by Doll *et al.*[7], where women had a greater responsiveness than did men. The two studies were both cross-sectional but they were not based on the same ethnic groups. Also, Doll did not consider the effect of collinearity between obesity measures. The two factors may partly explain the differences.

The present study had a very large sample size, which made it possible to perform statistical analyses using more than one method and made the results more convincing. Consistent results from different statistical methods, including logistic regression models and ROC curve analyses, contributed to the reliability of the findings. Moreover, multicollinearity between obesity measures was avoided in statistical analysis to a large extent. However, the present study also has some limitations. First, histories of diseases were self-reported and no blood test was performed. Second, although the sample size was very large, the population studied was limited to Chinese in China mainland. Therefore we could not obtain results across different ethnic groups. Besides, the limitation of the cross-sectional design was also a fact in our study. The relative ratio of anthropometric indices for blood pressures and incidence of hypertension could not be calculated. Longitudinal studies with large sample size and a follow-up with the present study are needed to further explore these questions.

Conclusion

All anthropometric indices for obesity were positively correlated with blood pressure and the presence of hypertension in this representative Chinese sample. After adjusting for age or for age and other factors, WSR in men and BMI in women had a greater association with hypertension than other simple obesity measures. Therefore we may infer that WSR for males and BMI for females should be recommended as good predictors for hypertension. BMI had the strongest correlation with continuous blood pressures in both genders. There exists a major difference between men and women, which has never been revealed by previous studies, regarding the issue of which obesity measure is the best indicator for hypertension. We may not hope to use a universal good indicator of obesity for hypertension and/or blood pressure in both genders. Visceral obesity tends to be more important in men with regard to hypertension, while in women the better indicator for hypertension should be overall obesity.

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Author contributions: Z.Z., D.H. and J.C. designed and supervised the research. Z.Z. and J.C. performed data checking work and statistical analyses. Z.Z. and D.H. did main preparation work for the paper. Z.Z. and J.C. acted as monitors during the screening work.

References

1. Flegal KM, Carroll MD, Ogden CL & Johnson CL (2002) Prevalence and trends in obesity among US adults, 1999–2000. *JAMA* **288**, 1723–1727.
2. Mokdad AH, Ford ES, Bowman BA, Dietz WH, Vinicor F, Bales VS & Marks JS (2003) Prevalence of obesity, diabetes, and obesity-related health risk factors, 2001. *JAMA* **289**, 76–79.
3. Lamon-Fava S, Wilson PW & Schaefer EJ (1996) Impact of body mass index on coronary heart disease risk factors in men and women – The Framingham offspring study. *Arterioscler Thromb Vasc Biol* **16**, 1509–1515.
4. Wilson PW, D'Agostino RB, Sullivan L, Parise H & Kannel WB (2002) Overweight and obesity as determinants of cardiovascular risk: the Framingham experience. *Arch Intern Med* **162**, 1867–1872.
5. Okosun IS, Chandra KM, Choi S, Christman J, Dever GE & Prewitt TE (2001) Hypertension and type 2 diabetes comorbidity in adults in the United States: risk of overall and regional adiposity. *Obes Res* **9**, 1–9.
6. Siani A, Cappuccio FP, Barba G, Trevisan M, Farinaro E, Lacone R, Russo O, Russo P, Mancini M & Strazzullo P (2002) The relationship of waist circumference to blood pressure: the Olivetti Heart Study. *Am J Hypertens* **15**, 780–786.
7. Doll S, Paccaud F, Bovet P, Burnier M & Wietlisbach V (2002) Body mass index, abdominal adiposity and blood pressure: consistency of their association across developing and developed countries. *Int J Obes Relat Metab Disord* **26**, 48–57.
8. Dyer AR, Liu K, Walsh M, Kiefe C, Jacobs DR Jr & Bild DE (1999) Ten-year incidence of elevated blood pressure and its predictors: the CARDIA Study Coronary Artery Risk Development in (Young) Adults. *J Hum Hypertens* **13**, 13–21.
9. Guagnano MT, Ballone E, Colagrande V, Della Vecchia R, Manigrasso MR, Merlitti D, Riccioni G & Sensi S (2001) Large waist circumference and risk of hypertension. *Int J Obes Relat Metab Disord* **25**, 1360–1364.
10. Kanai H, Matsuzawa Y, Kotani K, Keno Y, Kobatake T, Nagai Y, Fujioka S, Tokunaga K & Tarui S (1990) Close correlation of intraabdominal fat accumulation to hypertension in obese women. *Hypertension* **16**, 484–490.
11. Huang B, Rodreiguez BL, Burchfiel CM, Chyou PH, Curb JD & Sharp DS (1997) Associations of adiposity with prevalent coronary heart disease among elderly men: The Honolulu heart program. *Int J Obes Relat Metab Disord* **21**, 340–348.
12. Willett W (1990) *Nutritional Epidemiology*, pp. 217–244. New York: Oxford University Press.
13. Zhu S, Wang Z, Heshka S, Heo M, Faith MS & Heymsfield SB (2002) Waist circumference and obesity-associated risk factors among whites in the third National Health and Nutrition Examination Survey: clinical action thresholds. *Am J Clin Nutr* **76**, 743–749.
14. Valdez R (1991) A simple model-based index of abdominal adiposity. *J Clin Epidemiol* **44**, 955–956.
15. Ho SY, Lam TH & Janus ED, Hong Kong Cardiovascular Risk Factor Prevalence Study Steering Committee (2003) Waist to stature ratio is more strongly associated with cardiovascular risk factors than other simple anthropometric indices. *Ann Epidemiol* **13**, 683–691.
16. Savva SC, Tornaritis M, Savva ME, Kourides Y, Panagi A, Silikiotou N, Georgiou C & Kafatos A (2000) Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. *Int J Obes Relat Metab Disord* **24**, 1453–1458.
17. Mark AL, Correia M, Morgan DA, Shaffer RA & Haynes WG (1999) Obesity induced hypertension: new concepts from the emerging biology of obesity. *Hypertension* **33**, 537–541.
18. Yalcin BM, Sahin EM & Yalcin E (2005) Which anthropometric measurement is most closely related to elevated blood pressure? *Fam Pract* **22**, 541–547.
19. Fuchs FD, Gus M, Moreira LB, Moraes SR, Wiehe M & Pereira GM (2005) Anthropometric indices and the incidence of hypertension: a comparative analysis. *Obes Res* **13**, 1515–1517.
20. Yasmin & Mascie-Taylor CGN (2000) Adiposity indices and their relationship with some risk factors of coronary heart disease in middle aged Cambridge men and women. *Ann Hum Biol* **27**, 239–248.
21. Ghosh JR & Bandyopadhyay AR (2007) Comparative evaluation of obesity measures: relationship with blood pressures and hypertension. *Singapore Med J* **48**, 232–235.
22. Zhou ZQ, Hu DY, Chen J, Zhang RH, Li KB & Zhao XL (2004) An epidemiological survey of atrial fibrillation in China. *Zhonghua Nei Ke Za Zhi* **43**, 491–494.
23. Weiner JS & Lourie JA (1981) *Practical Human Biology.* New York: Academic Press.
24. Liu LS & Gong LS (2000) Guidelines for prevention and treatment for hypertension in China (trial version). *Chin J Hypertens* **8**, 94–102.
25. Kannel WB, Brand M, Skinner JJ Jr, Dawber TR & McNamara PM (1967) The relation of adiposity to blood

pressure and development of hypertension: the Framingham study. *Ann Intern Med* **67**, 48–59.

26. Spiegelman D, Israel R, Bouchard C & Willett W (1992) Absolute fat mass, percent body fat, and body fat distribution: which is the real determinant of blood pressure and serum glucose? *Am J Clin Nutr* **55**, 1033–1044.
27. Tanaka S & Togo M (1990) Relationship of fat mass and fat distribution to blood pressure. *Diabetes Res Clin Pract* **10**, Suppl. 1, S199–S203.
28. Ashwell M, Cole TJ & Dixon AK (1996) Ratio of waist circumference to height is strong predictor of intra-abdominal fat. *BMJ* **313**, 559–560.