Prediction of hypertension by different anthropometric indices in adults: the change in estimate approach

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Abstract

Objective: To examine the relative contribution for the prediction of hypertension by waist circumference (WC), waist:stature ratio (WSR) or waist:hip ratio (WHR) with that by BMI, to ascertain if WC, WSR or WHR enhances the prediction of hypertension by BMI.

Design: Population-based, cross-sectional study. A change of $\geq 10\%$ in the prevalence ratio of BMI (PR) or the area under the receiver-operating characteristic curve (AUC) when WC, WSR or WHR was added to a model with BMI was used as the criterion for significant contribution to the prediction of hypertension by BMI. For greater contributions ($\geq 10\%$) these waist measures were considered as better predictors.

Setting: Nine provinces in China.

Subjects: Chinese adults aged 18 to 65 years (n 7336) who participated in the 2004 China Health and Nutrition Survey.

Results: The prevalence of hypertension (17% and 23% for women and men, respectively) was significantly related to increased BMI, WC, WSR and WHR (P for trend <0.001). Although there was a better model fit when WC, WSR or WHR was added to a model with BMI ($P < 0.05$; likelihood ratio test), the changes in PR and AUC were $<10\%$ and $<5\%$, respectively. The sex-specific AUC for the prediction of hypertension by BMI (of $0.7–0.8$) was similar to that by WC, WSR or WHR.

Conclusions: The waist indices do not perform better than BMI or markedly enhance the prediction of increased hypertension risk by BMI in Chinese adults.

Anthropometric indicators for body fat are widely used to predict increased chronic disease risk at the individual and population level. Compared with BMI, which is a good indicator for body fatness in adults at the population level, waist circumference (WC), waist:stature ratio (WSR) and waist:hip ratio (WHR) provide additional information about central fat distribution[1,2]. Studies aimed at determining whether WC, WHR and WSR predict hypertension better than BMI or add to the prediction of hypertension have shown controversial results in both Western[3–5] and Asian populations[6–12]. As a criterion for judging predictions of alternative indicators these studies used a larger point estimate, a P value <0.05 or a non-overlap of 95% confidence intervals. Because P values and 95% confidence intervals are driven by both the magnitude of effect and the sample size[13,14], different conclusions would result from different sample sizes or BMI distributions.

The present study undertook a comparison of the predictive ability of these alternative indicators as they relate to Chinese adults. We utilized two criteria that are less affected by sample size, the difference in prevalence ratio and the area under the receiver-operating characteristic curve[15,16], to: (i) compare the prediction of hypertension by WC, WSR or WHR with that by BMI; and (ii) determine if WC, WSR or WHR enhances the prediction of hypertension by BMI in 18- to 65-year-old Chinese adults.

Methods

Study sample

We used data from the China Health and Nutrition Survey (CHNS) conducted in 2004 with a representative sample drawn from nine provinces in China (Guangxi, Guizhou, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Liaoning and Shandong). This sample was diverse, with variation found in a wide-ranging set of socio-economic factors (income, employment, education and modernization) and other related health, nutritional and demographic measures[17,18]. Of the 8258 participants aged 18 to 65 years who were men, non-pregnant or non-lactating women, 7336 (89%) had complete and plausible measurements of

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weight, height, WC, hip circumference (HC) and blood pressure (e.g. BMI of 15–35 kg/m^2, weight of 30–150 kg, height of 130–190 cm, WC of 45–150 cm, HC of 55–155 cm, WHR of 0·6–1·1, difference between systolic and diastolic blood pressure ≥10 mmHg). We only included 18- to 65-year-old adults, non-pregnant and non-lactating women because adolescents, the elderly, and pregnant or lactating women require different BMI and WC cut-offs[19]. The exclusion of participants with extreme values in anthropometric measurements and blood pressure helped to increase the estimate precision without changing the overall results.

Measurements

Three blood pressure measurements were taken in a seated position and on the right arm by trained health workers who followed a standardized procedure using regularly calibrated mercury sphygmomanometers with appropriate-sized cuffs. Systolic blood pressure was measured at the first appearance of a pulse sound (Korotkoff phase 1) and diastolic blood pressure at the disappearance of the pulse sound (Korotkoff phase 5). Three measurements of systolic or diastolic blood pressure were averaged to reduce the effect of measurement error. Hypertension was defined as systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥90 mm Hg or being previously diagnosed by a doctor[20]. The definition of hypertension was not based on the use of an antihypertensive medication because, in the present sample, a small proportion of Chinese adults were diagnosed (<7 %) or treated (<5 %) with an antihypertensive medication and none used an antihypertensive medication without being diagnosed by a doctor. Moreover, sensitivity analysis showed that incorporating these measures produced similar findings.

BMI was calculated based on weight and height measured by trained health workers who followed standardized procedures using regularly calibrated equipment (SECA 880 scales and SECA 206 wall-mounted metal tapes). The health workers used a non-elastic tape to measure WC at a point midway between the lowest rib and the iliac crest in a horizontal plane and HC at the point yielding the maximum circumference over the buttocks[17,18]. WSR (WC/height) and WHR (WC/HC) were calculated based on the measured WC, height and HC. Covariates such as age, sex, smoking habits, alcohol consumption and place of residence were collected by direct interviews.

Statistical analysis

We used Poisson regression models to examine the association between BMI and hypertension. Potential confounding factors, such as age (centred at the mean age of 45 years), sex, smoking habits (dichotomized to never smoker or ever smoker), alcohol consumption (dichotomized to current drinker or non-drinker) and place of residence (urban or rural), were also taken into account

in regression models. A covariate was considered as an effect measure modifier if its interaction term with BMI in regression models had a P value of <0·15 (χ^2 test) or as a confounder if it caused a change in prevalence ratios of BMI (PR) of ≥10 %[15]. Based on these criteria, age was the only effect measure modifier and there were no confounders. To make our results comparable with those of other studies, we stratified our analyses by sex in crude, age-adjusted and age-specific models. BMI, WC, WSR and WHR were kept in continuous scale to maximize the power of statistical tests.

The receiver-operating characteristic (ROC) curve is an analytical approach to define the highest combination of sensitivity and specificity of a screening test. The approach has been widely used to determine a cut-off point for decision making (e.g. having a disease or not) in both public health and clinical settings[7,10,16]. The most common measurement to quantify the performance of a screening test is the area under the ROC curve (AUC), which shows the ability of a test to correctly classify those with and without the disease. For example, an AUC value of 0·75 indicates that, 75 % of the time, a randomly selected individual from the diseased group has a test value larger than that for a randomly selected individual from the non-diseased group. AUC values range from 0·5 (no prediction) to 1·0 (perfect prediction). The AUC values are usually used as criteria to compare overall performances of different screening tests[16]. In the current study, AUC values were estimated by using logistic regression models.

To determine if the inclusion of WC, WSR or WHR improved the prediction of hypertension by BMI, we estimated the change in sex-specific PR (from Poisson regression models) and sex-specific AUC (from logistic regression models) between a model with BMI + WC, BMI + WSR or BMI + WHR and a model with BMI alone. A change in PR or AUC of ≥10 % was used as a criterion for a significant contribution of WC, WSR or WHR to the prediction of hypertension by BMI. We separately compared sex-specific AUC between a model with WC, WSR or WHR and a model with BMI to examine if any was better than BMI in predicting hypertension; an increase of ≥10 % in AUC was used as a criterion for a superior prediction. We used the criterion of ≥10 % because it is arbitrarily used to determine a notable confounding factor[15].

To facilitate the comparison with previous studies that use P value as a decision criterion, we compared the fit of a model with BMI with that of a model with BMI + WC, BMI + WSR or BMI + WHR. A P value of <0·05 (likelihood ratio test) was used as the criterion for a significant increase in model fit. In addition, independent t tests (P value <0·05) were used to compare PR of BMI from different regression models (e.g. models hypertension = BMI + WC v. hypertension = BMI). We did not adjust for the cluster effects from the CHNS because the adjustment did not affect point estimates of PR or AUC, which were used to estimate percentage change in PR or AUC. To

evaluate if these findings were consistent at different BMI levels, we performed similar analyses for participants with BMI < 23 kg/m^2 and BMI ≥ 23 kg/m^2 (data are presented in Supplementary tables 1 and 2). All analyses were performed using the STATA statistical software package version 9·2 (Stata Inc., College Station, TX, USA).

Role of the funding sources and ethical considerations

The authors had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. The sponsors were not involved in the study design, the collection, analysis or interpretation of the data, the writing of the manuscript, or the decision to submit the manuscript for publication. Written informed consent was obtained from each participant for each CHNS round. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. The relevant Institutional Review Boards have reviewed and approved the study.

Results

The crude prevalence of hypertension among men of 23·0% (95% CI 21·6, 24·4%) was higher than that among women (16·8%; 95% CI 15·6, 18·0%; $P < 0·001$). The mean systolic and diastolic blood pressures were higher among men (122 and 80 mmHg, respectively) compared with women (118 and 77 mmHg; $P < 0·001$). Only a small proportion of the Chinese adults was diagnosed or treated with any antihypertensive medications (about 5%). A small proportion of hypertensive participants, identified by measured blood pressures, was diagnosed by a doctor (35%) or treated with an antihypertensive medication (25%). Men and women had similar mean (23 kg/m^2) and distribution of BMI. Men had higher means of WC, HC and WHR, but smaller mean WSR compared with women. The proportions of Chinese men who were smokers (58·8%) and alcohol drinkers (62·3%) were much higher than those of women (Table 1).

There was a significant trend of increased prevalence of hypertension with an increase in BMI, WC, WSR or WHR (P for trend $< 0·001$) in both men and women (Fig. 1).

On average, each unit increase in BMI was associated with an 18% and 14% increase in PR for hypertension in women and men, respectively ($P < 0·001$; crude models). There was about a 15% increase in PR associated with each unit increase in BMI in age-adjusted and age-specific models ($P < 0·001$). Although there was an increase in model fit when adding WC, WSR or WHR to a model with BMI ($P < 0·05$ in almost all of the models; likelihood ratio test), the changes in PR were $< 10\%$ in the crude models and $< 5\%$ in the age-adjusted and age-specific models (Table 2). The changes in PR increased slightly

Table 1 Characteristics† of the 18- to 65-year-old Chinese participants‡

	Women (n 3794)		Men (n 3542)	
	Mean or %	95% CI	Mean or %	95% CI
Age (years)	44·0	43·6, 44·4	43·7	43·4, 44·1
Blood pressure status				
Hypertension§ (%)	16·8	15·6, 18·0	23·0*	21·6, 24·4
Hypertension diagnosed‖ (%)	6·6	5·8, 7·4	6·3	5·5, 7·1
Use antihypertensive medication¶ (%)	5·0	4·3, 5·7	4·1	3·4, 4·7
Systolic blood pressure (mmHg)	117·8	117·3, 118·4	122·1*	121·6, 122·6
Diastolic blood pressure (mmHg)	76·8	76·4, 77·1	80·1*	79·8, 80·4
BMI (kg/m^2)	23·1	23·0, 23·2	23·1	23·0, 23·2
<18·5 kg/m^2 (%)	6·0	5·2, 6·7	4·9	4·2, 5·7
18·5–22·9 kg/m^2 (%)	47·3	45·7, 48·8	48·0	46·3, 49·6
23·0–24·9 kg/m^2 (%)	19·7	18·4, 21·0	21·6	20·2, 23·0
≥25·0 kg/m^2 (%)	27·1	25·7, 28·5	25·5	24·1, 26·9
WC (cm)	78·7	78·4, 79·0	82·5*	82·2, 82·9
HC (cm)	93·2	92·9, 93·5	94·0*	93·7, 94·3
WHR	0·84	0·84, 0·85	0·88*	0·88, 0·88
WSR	0·50	0·50, 0·51	0·49*	0·49, 0·50
Smoking status				
Former smoker (%)	0·1	0·0, 0·2	5·6*	4·8, 6·3
Current smoker (%)	3·1	2·6, 3·7	58·8*	57·1, 60·4
Alcohol drinker (%)	9·0	8·0, 9·9	62·3*	60·7, 63·9
Urban residence (%)	34·0	32·5, 35·5	33·9	32·3, 35·4

WC, waist circumference; HC, hip circumference; WHR, waist:hip ratio; WSR, waist:stature ratio.
Significantly different compared with women (independent t test for continuous variables or χ^2 test for categorical variables): *$P < 0·001$.
†Values are means or percentages with 95% confidence intervals.
‡The samples included participants who were 18- to 65-year-old men and women (not pregnant or lactating), for whom measurements of anthropometric indices and blood pressure were complete and plausible (e.g. BMI of 15–35 kg/m^2, weight of 30–150 kg, height of 130–190 cm, WC of 45–150 cm, HC of 55–155 cm, WHR of 0·6–1·1, difference between systolic and diastolic blood pressure ≥10 mmHg).
§Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or being diagnosed by a doctor.
‖Hypertension diagnosed: proportion of the population that was diagnosed as being hypertensive by a doctor.
¶Use anti-hypertensive medication: proportion of the population that used any antihypertensive medications.
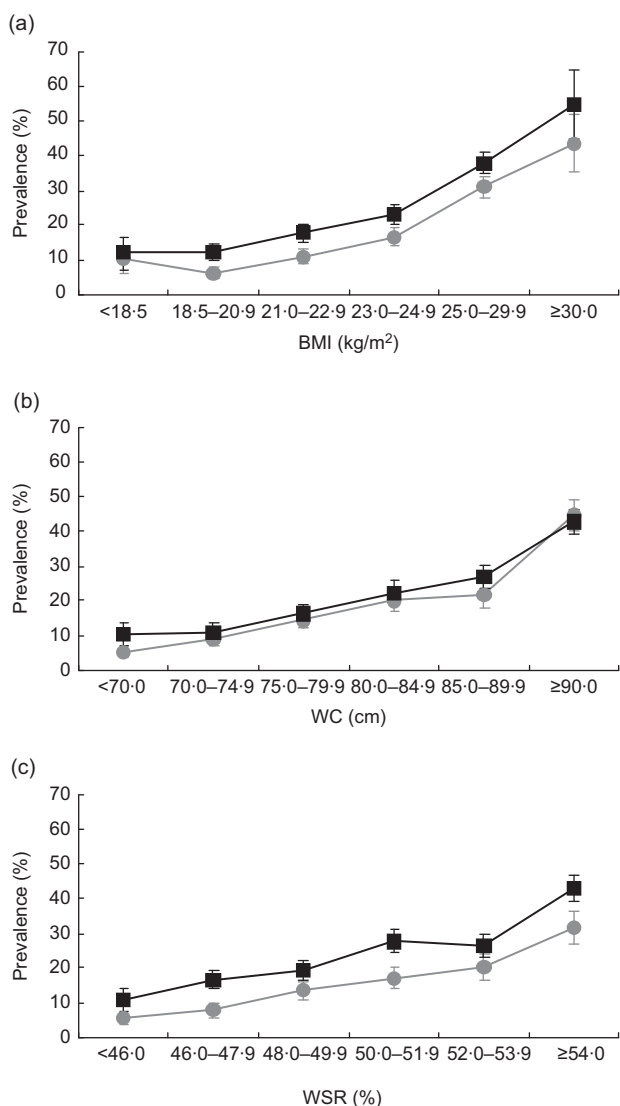
Fig. 1 Prevalence and 95 % CI of hypertension by levels of (a) BMI, (b) waist circumference (WC) and (c) waist:stature ratio (WSR). Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or being diagnosed by a doctor. The samples included participants who were 18- to 65-year-old men (■, *n* 3542) and women (●, not pregnant or lactating; *n* 3794), for whom measurements of anthropometric indices and blood pressure were complete and plausible (e.g. BMI of 15–35 kg/m², weight of 30–150 kg, height of 130–190 cm, WC of 45–150 cm, hip circumference of 55–155 cm, waist:hip ratio of 0·6–1·1, difference between systolic and diastolic blood pressure ≥10 mmHg). *P* for trend <0·001 for all

(<10 % except for WSR in the crude model for women) among participants with BMI < 23 kg/m² (Supplementary table 1).

The AUC estimates for the prediction of hypertension by BMI (about 0·7–0·8) were higher among women (*P* < 0·05 in age-adjusted and age-specific estimates). Although there was an increase in model fit when adding WC, WSR or WHR to a model with BMI (*P* < 0·05 in almost all of the models; likelihood ratio test), the changes

in AUC were <5 % in the crude models and <1 % in the age-adjusted and age-specific models (Table 3). The changes in AUC increased slightly (<10 % except for WSR in crude model for women) among participants with BMI < 23 kg/m² (Supplementary table 2).

Models with WC or WSR provided similar AUC compared with models with BMI for men, women and both sexes (difference in AUC < 2·5 %; *P* > 0·05). A model with WHR had about 4–10 % lower AUC compared with a corresponding model with BMI (Table 3). There were some increases (<10 % except for WSR in crude model for women) in the prediction of hypertension by WC, WSR and WHR compared with that by BMI among participants with BMI < 23 kg/m² (Supplementary table 2).

Discussion

To our knowledge, we are the first to use changes in PR and AUC as the criteria to evaluate whether WC, WSR or WHR adds to the prediction of hypertension by BMI in an Asian population. Our findings show that even though WC, WSR and WHR are predictors of hypertension and improve the fit of models with BMI, they do not perform better than BMI or add meaningfully to the prediction of hypertension outcome by BMI in Chinese adults.

We observed a significant trend of increased prevalence of hypertension with increased BMI, WC, WSR and WHR. This finding was similar to results from studies in Asian[6,7,9,10,21–25] and Western populations[5,26,27]. Increased blood pressure is associated with increased BMI because an increase in body weight and thus BMI is related to an increase in body fluid volume, peripheral resistance (e.g. hyperinsulinaemia, cell membrane alteration and hyperactivity of the rennin–angiotensin system lead to functional constriction and structural hypertrophy) and cardiac output[28]. The positive correlation between WC, WSR or WHR and prevalence of hypertension could be explained by an increase in visceral fat that leads to increased leptin and insulin resistance and worse lipid profiles[28,29].

There are several possible explanations for the finding that WC and WSR did not perform better or add to the prediction of hypertension by BMI in this population. First, WC and WSR were highly correlated with BMI (sex-specific Pearson correlation coefficients were about 0·75). The high correlation leads to a large overlap among the predictions explained by WC, WSR and BMI. Second, compared with other races and ethnicities, Asians accumulate more total body fat and visceral fat with an increase in body weight[30–32]. In addition, WC and WSR are only proxy indicators for total body fat and visceral fat[1] while increased visceral fat is a predictor for an increase in metabolic risk[2].

The findings that WC, WSR and WHR were not superior to BMI in the prediction of hypertension are consistent with those from a representative sample of 55 563 Taiwanese

Table 2 Sex-specific prevalence ratios of BMI for hypertension†,‡

Model	Independent variable	Women (n 3794)				Men (n 3542)			
		PR	95 % CI	% change§	P value‖	PR	95 % CI	% change	P value
Crude model¶	BMI	1·18	1·16, 1·20			1·14	1·12, 1·17		
	BMI + WC	1·08*	1·05, 1·11	8·8	<0·001	1·08*	1·05, 1·11	5·7	<0·001
	BMI + WSR	1·07*	1·04, 1·11	9·5	<0·001	1·06*	1·03, 1·10	7·1	<0·001
	BMI + WHR	1·15	1·13, 1·18	2·1	<0·001	1·11	1·09, 1·14	2·8	<0·001
Age-adjusted††	BMI	1·14	1·11, 1·16			1·14	1·12, 1·16		
	BMI + WC	1·10	1·06, 1·13	3·6	0·003	1·09	1·05, 1·12	4·7	<0·001
	BMI + WSR	1·11	1·07, 1·14	2·6	0·029	1·09	1·06, 1·13	4·1	<0·001
	BMI + WHR	1·13	1·11, 1·16	0·6	0·136	1·12	1·09, 1·14	2·0	<0·001
Age-specific‡‡	BMI	1·16	1·13, 1·20			1·15	1·12, 1·17		
	BMI + WC	1·12	1·08, 1·16	3·7	0·002	1·09	1·06, 1·13	4·7	<0·001
	BMI + WSR	1·13	1·09, 1·17	2·7	0·022	1·10	1·07, 1·14	4·1	<0·001
	BMI + WHR	1·16	1·13, 1·19	0·6	0·130	1·12	1·10, 1·15	2·0	<0·001

PR, prevalence ratio of BMI; WC, waist circumference; WHR, waist:hip ratio; WSR, waist:stature ratio.
Significantly different compared with PR of a model with BMI (independent t test): *$P < 0.05$.
†Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or being diagnosed by a doctor.
‡The samples included participants who were 18- to 65-year-old men and women (not pregnant or lactating), for whom measurements of anthropometric indices and blood pressure were complete and plausible (e.g. BMI of 15–35 kg/m^2, weight of 30–150 kg, height of 130–190 cm, WC of 45–150 cm, hip circumference of 55–155 cm, WHR of 0·6–1·1, difference between systolic and diastolic blood pressure ≥10 mmHg).
§% change = 100 × absolute[ln(PR$_{BMI}$/PR$_{Test\ variables}$)]; test variables were BMI + WC, BMI + WSR or BMI + WHR.
‖P value of the increase in model fit compared with a model with BMI (likelihood ratio test).
¶Crude models: include independent variables in the list; crude PR for each unit increase in BMI.
††Age-adjusted models: independent variables + age; age-adjusted PR for each unit increase in BMI.
‡‡Age-specific model: independent variables + age + (age × BMI); PR for each unit increase in BMI at the age of 45 years.

Table 3 Sex-specific AUC for the prediction of hypertension by different anthropometric indices†,‡

Model	Independent variable	Women (n 3794)			Men (n 3542)			Both sexes (n 7336)		
		AUC§	95 % CI	% change‖	AUC	95 % CI	% change	AUC	95 % CI	% change
Crude model¶	BMI	0·71	0·68, 0·73		0·67	0·65, 0·69		0·69	0·67, 0·70	
	WC	0·72	0·69, 0·74	1·1	0·67	0·65, 0·70	0·5	0·70	0·68, 0·71	1·9
	WSR	0·72	0·70, 0·74	2·2	0·68	0·66, 0·70	1·7	0·69	0·68, 0·71	1·1
	WHR	0·64*	0·61, 0·66	10·4	0·64	0·62, 0·67	4·1	0·65*	0·63, 0·66	5·9
	BMI + WC	0·73***	0·70, 0·75	2·5	0·68***	0·66, 0·70	1·9	0·71***	0·69, 0·72	3·0
	BMI + WSR	0·73***	0·71, 0·75	3·4	0·69***	0·67, 0·71	2·5	0·70***	0·69, 0·72	2·5
	BMI + WHR	0·72***	0·69, 0·74	1·3	0·68***	0·66, 0·71	2·0	0·70***	0·69, 0·72	2·2
Age-adjusted††	BMI	0·79	0·77, 0·81		0·74	0·72, 0·76		0·76	0·75, 0·78	
	WC	0·78	0·76, 0·80	1·0	0·74	0·72, 0·76	0·8	0·76	0·75, 0·77	0·1
	WSR	0·78	0·76, 0·80	1·5	0·73	0·72, 0·75	1·1	0·75	0·74, 0·76	1·8
	WHR	0·75	0·73, 0·77	4·8	0·72	0·70, 0·74	3·8	0·73*	0·72, 0·75	3·8
	BMI + WC	0·79***	0·78, 0·81	0·3	0·75***	0·73, 0·77	0·7	0·77***	0·76, 0·78	0·9
	BMI + WSR	0·79**	0·77, 0·81	0·2	0·75***	0·73, 0·77	0·5	0·76***	0·75, 0·78	0·2
	BMI + WHR	0·79^{NS}	0·77, 0·81	0·1	0·75***	0·73, 0·77	0·6	0·77***	0·75, 0·78	0·6
Age-specific‡‡	BMI	0·79	0·77, 0·81		0·74	0·72, 0·76		0·76	0·75, 0·78	
	BMI + WC	0·79***	0·78, 0·81	0·3	0·75***	0·73, 0·77	0·7	0·77***	0·76, 0·78	0·9
	BMI + WSR	0·79**	0·77, 0·81	0·2	0·75***	0·73, 0·77	0·5	0·76***	0·75, 0·78	0·2
	BMI + WHR	0·79^{NS}	0·77, 0·81	0·1	0·75***	0·73, 0·77	0·6	0·77***	0·75, 0·78	0·6

AUC, area under the receiver-operating characteristic curve; WC, waist circumference; WSR, waist:stature ratio; WHR, waist:hip ratio.
Significantly different compared with a model with BMI (independent t test): * $P < 0.05$.
Significant increase in model fit compared with BMI (likelihood ratio test): **$P < 0.005$, ***$P < 0.001$, NS, $P = 0.07$.
†Hypertension was defined as systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg or being diagnosed by a doctor.
‡The samples included participants who were 18- to 65-year-old men and women (not pregnant or lactating), for whom measurements of anthropometric indices and blood pressure were complete and plausible (e.g. BMI of 15–35 kg/m^2, weight of 30–150 kg, height of 130–190 cm, WC of 45–150 cm, hip circumference of 55–155 cm, WHR of 0·6–1·1, difference between systolic and diastolic blood pressure ≥10 mmHg).
§AUC values range from 0·5 (no prediction) to 1·0 (perfect prediction); estimated by using logistic regression models.
‖% change = 100 × absolute[ln(AUC$_{BMI}$/AUC$_{Test\ variables}$)]; test variables were WC, WSR, WHR, BMI + WC, BMI + WSR or BMI + WHR.
¶Crude models: include independent variables in the list.
††Age-adjusted models: independent variables + age.
‡‡Age-specific model: independent variables + age + (age × BMI).

in a study by Lin *et al.*[10]. Their protocols for the measurements of weight, height, WC, HC and blood pressures were similar to ours. Based on their data, we computed the difference in AUC based on the sex-specific AUC of each risk factor or disease condition (e.g. hypertension, diabetes mellitus, dislipidaemia, elevated TAG, total cholesterol or LDL cholesterol, or decreased HDL cholesterol). WC, WSR or WSR was not superior (<10 %

increase in AUC) to BMI in the prediction of any risk factors or disease conditions in women or men.

We also computed the difference in AUC with the use of sex-specific AUC from a sample of 2895 Hong Kong Chinese in a study by Ho et al.[7]. WC provided similar predictions to BMI in the examined diseases and metabolic risk factors (except for stroke in women), while WHR and WSR were better than BMI in some predictions (e.g. hypertension and CVD (men); dislipidaemia (women); and fasting glucose, diabetes and stroke (men and women)). There are three potential explanations for the differences. First, the study by Ho et al.[7] was based on a non-representative sample: participants were recruited by telephone (response rate of 78%), and only 38% of responders were examined and included in the final sample. Those participants might have very different disease patterns, risk factors and health-related behaviours compared with the non-participants[33]. Second, Ho et al.'s study[7] included 65- to 74-year-old participants who might have: (i) a lower WC measured at a high location (Ho et al. measured WC at midway between the xiphisternum and the umbilicus), which would underestimate abdominal fat and overestimate the prediction of WC; and (ii) a higher BMI due to a biological decrease in height which would underestimate the prediction of BMI. As a result, there would be an increase in the prediction of WC, WSR or WHR compared with BMI. Third, WC measured in the Ho et al.'s study[7] was systematically smaller than ours (we measured WC midway between the lowest rib and the iliac crest)[34]. Decreased WSR and WHR, resulting from the smaller WC, would bias the association between WSR and WHR away from the null and would increase their predictions compared with that of BMI.

Our study showed a tendency toward increased prediction of hypertension by WC, WSR or WHR among participants with a lower BMI (e.g. BMI $< 23\,\mathrm{kg/m^2}$). The finding is consistent with those of Ardern et al.[35], in which the association between WC and cardiovascular risk was stronger at a lower BMI. However, the studies are not directly comparable. Their sample included American (white, black and Hispanic) and Canadian participants who differed from our Chinese participants in age, body composition, lifestyles and socio-economic characteristics. Also, Ardern et al.[35] used the Framingham CHD risk index as study outcome, while we used hypertension.

We would have concluded that WC, WSR or WHR added to the prediction of hypertension by BMI (this finding being consistent with other studies[5,9,12]) if a P value of <0.05 in a likelihood ratio test had been used as a decision criterion. However, this criterion is not the best choice because a P value varies with both the magnitude of effect and the sample size[13,14]. For example, with a large sample size, we could detect a small difference (e.g. P value <0.05); in contrast, with a small sample size, we may not detect a large difference (e.g. P value >0.05). Our methods are expected to be more stable to the variation in sample size because the estimations of PR, AUC and the change in those estimates are less likely to be affected by the changes sample size[15,16]. In addition, our sensitivity analyses, in which samples of 50% and 10% of the original sample were selected randomly, showed that P value is more sensitive to changes in sample size than is percentage change in PR and AUC.

In the context of a developing country, it is important to find a small number of practical, low-cost and culturally accepted anthropometric indices to predict elevated disease burdens[36,37]. In a population or clinical setting among Chinese adults, BMI appears to be sufficient because: (i) the exclusion of WC will save time, money and human resources; and (ii) the interpretation of a WC value would be confusing because of the lack of a universally accepted site for measuring WC and the large variation of WC optimal cut-offs by sex, age, races, ethnicities, BMI levels and health outcomes of interest[2]. Even in the USA, most of the treatment recommendations (99.9% for men and 98.5% for women; data from the Third National Health and Nutrition Examination Survey) were based on the evaluation of BMI and cardiovascular risk factors, regardless of the measured WC[38].

In conclusion, the present study showed that even though WC, WSR and WHR are predictors of hypertension, they do not perform better than BMI or add to the prediction of hypertension by BMI in Chinese adults. The comparison of PR and AUC, instead of P value or 95% CI, is considered a strength and a methodological contribution of the present study. Further studies with other outcomes (e.g. glucose intolerance, diabetes mellitus, dyslipidaemia, mortality or events of CVD/non-communicable diseases) and more detailed information about body composition (e.g. total abdominal adipose tissue, visceral adipose tissue, total body fat mass) in representative samples of Chinese, other Asian and Western populations are still needed to confirm the consistency of the finding. Nevertheless, our conclusions about the value of using BMI to predict hypertension are meaningful for decision making in public health and clinical settings. Compared with WC, height and weight and thus BMI are: (i) collected more often in nutrition and health surveys, interventions and in clinics; (ii) collected with the use of universally accepted protocols; and (iii) easier to interpret.

Acknowledgements

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