Public Health Nutrition: 20(6), 984–991 doi:10.1017/S1368980016003281

Comparison of the ability to identify cardiometabolic risk factors between two new body indices and waist-to-height ratio among Chinese adults with normal BMI and waist circumference

Peng Ju Liu[1,*], Fang Ma[1], Hui Ping Lou[2] and Yan Ning Zhu[3]
[1]Departments of Clinical Nutrition, Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College, Beijing 100730, People's Republic of China: [2]Medical Examination Center, Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College, Beijing, People's Republic of China: [3]Obstetrics and Gynecology, Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College, Beijing, People's Republic of China

Submitted 19 May 2016: Final revision received 24 September 2016: Accepted 27 October 2016: First published online 19 December 2016

Abstract
Objective: Waist-to-height ratio (WHtR) has been reported to be more strongly associated with cardiometabolic risk factors among non-obese individuals than BMI and waist circumference (WC). A body shape index (ABSI) and body roundness index (BRI) have been proposed recently to assess obesity-related disorders or mortalities. Our aim was to compare the ability of ABSI and BRI with that of WHtR to identify cardiometabolic risk factors in Chinese adults with normal BMI and WC.
Design: Receiver-operating characteristic curves and areas under the curve (AUC) were employed to evaluate the ability of the indices (WHtR, BRI, ABSI) to identify metabolic risk factors and to determine the indices' optimal cut-off values. The value of each index that resulted in maximization of the Youden index (sensitivity + specificity – 1) was defined as optimal. Differences in the AUC values between the indices were also evaluated.
Setting: Individuals attending a voluntary health check-up in Beijing, China, July–December 2015, were recruited to the study.
Subjects: Non-obese adults (*n* 1596).
Results: Among both genders, ABSI exhibited the lowest AUC value for identifying each risk factor among the three indices; the AUC value of BRI for identifying each risk factor was very close to that of WHtR, and no significant differences were observed between the AUC values of the two new indices.
Conclusions: When evaluating cardiometabolic risk factors among non-obese adults, WHtR was a simple and effective index in the assessment of cardiometabolic risk factors, BRI could be used as an alternative body index to WHtR, while ABSI could not.

Keywords
Body roundness index
A body shape index
Cardiometabolic risk factor
Waist-to-height ratio
Non-obese

Obesity, an independent risk factor for CVD, is closely associated with elevated risk of diabetes, insulin resistance and other metabolic disorders[1,2]. The WHO defines obesity as an excessive accumulation of fat to an extent that may impair health[3]. Assessment of overweight and obesity includes examination of the distribution of body mass components and risk factors for diseases such as type 2 diabetes, dyslipidaemia, impaired glucose tolerance and CVD. Consequently, it is a major health concern to identify obesity in order to estimate the risk of associated disorders. However, obese people may vary in their body fat distribution and disease risk. The accumulation of visceral fat, as opposed to subcutaneous fat, increases the risk of metabolic diseases and CVD[4]. Therefore, it is currently accepted that the distribution of body fat, rather than the total amount of adipose tissue, is a crucial determinant of metabolic abnormalities[5]. MRI and computed tomography have been recognized as the gold standard for measuring the volume of visceral fat, but these two methods are not suitable for large-scale epidemiological studies due to their inconvenience and high cost[6]. Therefore, body fat is frequently estimated or reflected by a series of anthropometric indices in most studies.

Among different anthropometric measures, BMI is one of the most commonly used indices. While BMI is a widely

*Corresponding author: Email lpjjia@126.com

accepted and an early applicable measure of obesity, its use has limitations. BMI depends only on height and weight, and does not distinguish between adipose tissue and muscle mass[7]. As one study reported, at the same BMI value, MRI-measured body fat content varied from 7·8 to 38·3 % in men and from 29·9 to 44·2 % in women[8]. As well, at the same BMI value, individuals from different ethnic groups may exhibit very different body fat distributions. Several studies have reported that people from Asia have greater total body and abdominal fat distribution or a greater incidence of CVD and more metabolic risk factors than people from Europe for the same BMI or waist circumference (WC) value[9,10]. WC, an essential diagnostic component of the metabolic syndrome and a typical anthropometric parameter reflecting central obesity, is strongly related to CVD and a number of studies have demonstrated that WC predicts mortality risk better than BMI[11–15]. However, a recent systematic review demonstrated that waist-to-height ratio (WHtR) is a significantly more favourable screening tool for adult metabolic risk factors than are BMI and WC[16], and reported that compared with BMI, WC improved the discrimination of adverse cardiovascular risk outcomes by 3 % and WHtR improved discrimination by 4–5 %. As well, WHtR is able to evaluate cardiovascular risk factors and to effectively predict the incidence of metabolic syndrome in non-obese people[17–20]. However, the problem is that none of these indices alone is able to distinguish subcutaneous fat from the visceral fat which is more strongly associated with metabolic abnormalities. Some studies still suggest that these indices provide limited information on fat distribution[21–23].

Recently, a body shape index (ABSI), a new body index proposed by Krakauer and Krakauer[24], has been reported to be significantly associated with abdominal adipose tissue and to be more associated with premature death than either WC or BMI. In some cohort studies, ABSI showed a positive association with disease risk and mortality hazard[25,26]. However, some studies reported that ABSI seemed to be a weaker index for identifying hypertension, diabetes, CVD risk and metabolic syndrome than BMI[27–29]. Therefore, this controversy remains to be further studied. As far as we know, the efficacy of ABSI for identifying cardiometabolic risk factors in non-obese Chinese has not been specifically studied.

Body roundness index (BRI), another new index proposed by Thomas *et al.* and based on WC and height, is a predictor that could improve predictions of body fat percentage and visceral adiposity tissue compared with the traditional metrics of BMI, WC or hip circumference[30]. Several recent studies have shown that BRI could be used as an adipose indicator for determining the presence of eccentric left ventricular hypertrophy, hyperuricaemia, CVD and diabetes[27,31–33]. However, to date, little evidence has compared BRI with WHtR in the assessment of cardiometabolic risk factors in non-obese Chinese adults.

Therefore, it is necessary to assess whether the new indices better identify cardiometabolic risk factors than the traditional ones. The objective of the present study was to compare the ability of ABSI and BRI with that of WHtR to identify cardiometabolic risk factors in Chinese adults with normal BMI and WC.

Methods

Participants

From July to December 2015, a total of 1596 non-obese people aged 20–60 years (with normal BMI (in the range of 18·5 to 23·9 kg/m^2) and WC (male < 90 cm, female < 80 cm)) who voluntarily visited the Medical Examination Center of Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College (Beijing, China) for a health check-up were recruited for the present study. The mean age of the study participants was 44·4 (SD 8·1) years. All participants were of Han ethnicity and dwelled in the communities of Beijing, China. The exclusion criteria were as follows: (i) evidence of liver or renal insufficiency or malignancy; (ii) a medication history of corticosteroids or hormone therapy in the previous 6 months; (iii) those on a weight-loss programme or who had lost ≥5 % of their body weight in the previous 12 months; (iv) current hyperthyroidism or hypothyroidism or oedema; (v) skeletal deformities or amputations or dependence on wheelchairs or other ambulatory assistive devices; (vi) men whose alcohol consumption more than 14 ethanol units (1 ethanol unit = 14 g ethanol) per week and women whose alcohol consumption was more than 10 ethanol units per week; and (vii) women who were pregnant.

The study was approved by the Ethics Committee of Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College. All participants provided written informed consent before participating in the study.

Procedure

Trained physicians administered a standard questionnaire to collect information on age, smoking status (yes/no), alcohol consumption, weight status, medical history and medication use. Routine physical examinations were then performed for all participants. Two blood pressure (BP) recordings (rounded to the nearest 2 mmHg) were obtained from the right arm of the participants while seated after 30 min of rest. The final measurement was the average of these two recordings.

Anthropometric measurements

Participants were requested to wear light clothing and take off their shoes for the measurement of their anthropometric characteristics, which was performed by well-trained examiners. Height was measured

https://doi.org/10.1017/S1368980016003281 Published online by Cambridge University Press

(rounded to the nearest 0·1 cm) using a portable stadiometer. Body weight was measured (rounded to the nearest 0·1 kg) using a calibrated scale with the participant in an upright position. BMI was calculated by dividing weight by the square of height (kg/m^2). WC was measured (rounded to the nearest 0·1 cm) at the end of normal expiration at the midpoint between the lower border of the rib cage and the iliac crest. WHtR was calculated by dividing waist circumference by height. ABSI and BRI were calculated using the corresponding formula as follows[24,31]:

$$\text{ABSI} = \frac{\text{WC}}{\text{BMI}^{2/3}\text{height}^{1/2}}$$

and

$$\text{BRI} = 364 \cdot 2 - 365 \cdot 5 \times \sqrt{1 - \left(\frac{(\text{WC}/2\pi)^2}{(0 \cdot 5 \times \text{height})^2}\right)}.$$

Biochemical measurements

Blood samples were collected from the peripheral vein of all participants in the morning after a fasting period of 10–12 h. After collection, the samples were immediately centrifuged at 4°C. The plasma was assayed for the lipid profile (including total cholesterol, TAG, LDL cholesterol and HDL cholesterol (HDL-C)), fasting blood glucose (FBG) and high-sensitivity C-reactive protein (hs-CRP) using an automated analyser (Olympus AU5800, Japan).

Definition of cardiometabolic risk factors

In present study, the cardiometabolic risk factors included high BP, dyslipidaemia and dysglycaemia. Both pre-hypertension and hypertension were considered as high BP; pre-hypertension was defined as systolic blood pressure (SBP) of 120–139 mmHg or diastolic blood pressure (DBP) of 80–89 mmHg[34]; and hypertension was defined as SBP ≥ 140 mmHg or DBP ≥ 90 mmHg or currently receiving antihypertensive medication. Dysglycaemia included pre-diabetes and diabetes. The definition of pre-diabetes was FBG greater than 5·6 mmol/l and less than 7·0 mmol/l, and no history of diabetes or use of antidiabetes medication; and diabetes was defined as FBG ≥ 7·0 mmol/l or a history of type 2 diabetes previously[35,36]. Dyslipidaemia included high TAG (≥1·71 mmol/l) and low HDL-C (≤1·03 mmol/l for men or ≤1·30 mmol/l for women)[37].

Statistical analyses

Statistical analyses were performed using the statistical software package SPSS version 16.0. Data are expressed as mean and standard deviation for continuous variables and as frequency and percentage for categorical variables. The independent-samples *t* test was used to compare basic characteristics between males and females. The data of males and females were then analysed separately. Partial correlations were applied to assess the correlations between the body indices and metabolic variables including SBP, DBP, TAG, HDL-C and FBG with controlling for age and hs-CRP. Participants were divided into four groups according to the number of metabolic risk factors (0, 1, 2, ≥3) and univariate analysis was then applied to compare the mean value of body indices in the four groups among both genders with controlling for smoking and drinking status, age and hs-CRP. Receiver-operating characteristic (ROC) curves and areas under the curve (AUC) were employed to evaluate the ability of the three body indices to identify the risk factors and to determine the optimal cut-off values of anthropometric indices; the values of the indices that maximized the Youden index (sensitivity + specificity – 1) were defined as optimal. A comparison of the diagnostic abilities between WHtR and the two new body indices was performed using the AUC, and the significance of the difference between two AUC values was assessed by the method described by Hanley and McNeil[38].

Results

The basic characteristics of the study population are shown in Table 1. Compared with females, males exhibited a significantly higher age, BMI, WC, WHtR, BRI, ABSI, SBP, DBP, total cholesterol, TAG, LDL cholesterol, FBG, hs-CRP and current smoking and smoking rate, but lower HDL-C; in addition, a significantly higher prevalence was observed for high BP, high TAG and dysglycaemia among males. The prevalence of low HDL-C was significantly lower in males than in females.

As shown in Table 2, in males, after controlling for age and hs-CRP, partial correlation analysis showed that both BRI and WHtR were positively associated with SBP, DBP and TAG, and were not correlated with FBG. Conversely, BRI and WHtR were negatively correlated with HDL-C; ABSI did not correlate with any metabolic variable (including SBP, DBP, TAG, HDL-C and FBG). In females, after age and hs-CRP were controlled, both BRI and WHtR were positively associated with SBP and TAG, and were not correlated with DBP and FBG. However, they were negatively correlated with HDL-C. Interestingly, ABSI was negatively associated with SBP and TAG, but positively with HDL-C.

As shown in Table 3, in males, the mean value of WHtR and BRI increased significantly (*P* for trend <0·001) with the increase in the number of risk factors after controlling for smoking and drinking status, age and hs-CRP, but ABSI did not exhibit a progressive increase in parallel with increased number of risk factors. In females, the mean values of the three indices increased significantly with the increase in the number of risk factors after controlling for smoking and drinking status, age and hs-CRP.

Table 1 Characteristics of the study participants according to gender: non-obese adults (*n* 1596) attending a voluntary health check-up in Beijing, China, July–December 2015

	Males (*n* 711)		Females (*n* 885)		
Variable	Mean	SD	Mean	SD	*P* value
Age (years)	45·5	7·9	43·5	8·1	<0·001
BMI (kg/m^2)	22·4	1·3	21·6	1·4	<0·001
WC (cm)	81·6	3·2	73·0	3·1	<0·001
WtHR	0·47	0·02	0·45	0·03	<0·001
BRI	2·8	0·4	2·5	0·4	<0·001
ABSI	0·0779	0·0018	0·0740	0·0017	<0·001
SBP (mmHg)	117	12·1	110	12·6	<0·001
DBP (mmHg)	74	9·5	67	8·3	<0·001
TC (mmol/l)	5·02	0·91	4·86	0·86	<0·001
TAG (mmol/l)	1·67	1·12	1·06	0·60	<0·001
HDL-C (mmol/l)	1·24	0·29	1·46	0·31	<0·001
LDL-C (mmol/l)	3·14	0·80	2·91	0·73	<0·001
FBG (mmol/l)	5·3	1·2	5·0	0·7	<0·001
hs-CRP (mg/l)	1·1	1·6	0·8	1·3	<0·001
	%		%		
Prevalence of high BP (%)	42·3		21·7		<0·001
Pre-hypertension (%)	26·3		14·4		<0·001
Hypertension (%)	16·0		7·3		<0·001
Prevalence of dysglycaemia (%)	22·4		10·6		<0·001
Pre-diabetes (%)	12·6		7·2		<0·001
Diabetes (%)	9·8		3·4		<0·001
Prevalence of high TAG (%)	32·8		11·2		<0·001
Prevalence of low HDL-C (%)	24·5		32·0		0·001
Current drinker (%)	43·6		11·2		<0·001
Current smoker (%)	41·2		10·8		<0·001

WC, waist circumference; WtHR, waist-to-height ratio; BRI body roundness index; ABSI, a body shape index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; HDL-C, HDL cholesterol; LDL-C, LDL cholesterol; FBG, fasting blood glucose; hs-CRP, high-sensitivity C-reactive protein; BP, blood pressure.

Table 2 Partial correlations between body indices and metabolic components according to gender among non-obese adults (*n* 1596) attending a voluntary health check-up in Beijing, China, July–December 2015

	WHtR†		BRI†		ABSI†	
	Coefficient	*P* value	Coefficient	*P* value	Coefficient	*P* value
Males						
SBP (mmHg)	0·111	0·003	0·111	0·003	−0·020	0·587
DBP (mmHg)	0·130	0·001	0·132	<0·001	−0·003	0·944
TAG (mmol/l)	0·169	<0·001	0·172	<0·001	−0·066	0·079
HDL-C (mmol/l)	−0·140	<0·001	−0·143	<0·001	−0·012	0·747
FBG (mmol/l)	0·042	0·268	0·044	0·241	0·040	0·290
Females						
SBP (mmHg)	0·080	0·017	0·082	0·015	−0·090	0·007
DBP (mmHg)	0·050	0·141	0·050	0·136	−0·050	0·142
TAG (mmol/l)	0·132	<0·001	0·128	<0·001	−0·084	0·013
HDL-C (mmol/l)	−0·162	<0·001	−0·159	<0·001	0·096	0·004
FBG (mmol/l)	0·065	0·054	0·059	0·081	−0·045	0·182

WtHR, waist-to-height ratio; BRI, body roundness index; ABSI, a body shape index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, HDL cholesterol; FBG, fasting blood glucose.
†Controlling for age and high-sensitivity C-reactive protein.

The AUC values for discriminating high BP, dysglycaemia, high TAG and low HDL-C by WHtR, BRI and ABSI for males and females are shown in Table 4. In males, with regard to dysglycaemia, high TAG and low HDL-C, the AUC value for BRI was slightly higher than that for WHtR (0·556 *v.* 0·550; 0·628 *v.* 0·625; 0·600 *v.* 0·598, respectively), but the AUC value for BRI regarding high BP was slightly lower than that for WHtR (0·587 *v.* 0·589). In females, the AUC value for WHtR was slightly larger regarding high BP, dysglycaemia and high TAG than for BRI (0·619 *v.* 0·618; 0·619 *v.* 0·614; 0·639 *v.* 0·638, respectively); the AUC value for WHtR was equal to that for BRI in identifying low HDL-C.

According to the ROC curve analysis, ABSI obviously exhibited the lowest AUC value for identifying each cardiometabolic risk factor among the three indices and

Table 3 Mean value of each body index, and its standard deviation, according to the number of cardiometabolic risk factors and gender among non-obese adults (*n* 1596) attending a voluntary health check-up in Beijing, China, July–December 2015

	Males						Females					
	WHtR†		BRI†		ABSI†		WHtR†		BRI†		ABSI†	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0 risk factors	0·46	0·03	2·7	0·4	0·0778	0·0017	0·45	0·03	2·4	0·4	0·0739	0·0015
1 risk factor	0·47	0·02	2·8	0·4	0·0778	0·0016	0·46	0·02	2·5	0·4	0·0741	0·0015
2 risk factors	0·47	0·02	2·9	0·4	0·0778	0·0015	0·46	0·03	2·6	0·5	0·0741	0·0017
≥3 risk factors	0·48	0·02	3·0	0·4	0·0781	0·0013	0·47	0·02	2·8	0·4	0·0746	0·0016
P for trend	<0·001		<0·001		0·722		<0·001		<0·001		0·018	

WHtR, waist-to-height ratio; BRI, body roundness index; ABSI, a body shape index.
†Adjusted for smoking and drinking status, age and high-sensitivity C-reactive protein.

Table 4 Area under the receiver-operating characteristic curve (AUC), and its 95 % confidence interval, for the identification of cardiometabolic risk factors by each body index according to gender among non-obese adults (*n* 1596) attending a voluntary health check-up in Beijing, China, July–December 2015

	High BP		Dysglycaemia		High TAG		Low HDL-C	
	AUC	95 % CI	AUC	95 % CI	AUC	95 % CI	AUC	95 % CI
Males								
WHtR	0·589***	0·547, 0·631	0·550	0·501, 0·599	0·625***	0·583, 0·667	0·598***	0·550, 0·645
BRI	0·587***	0·545, 0·629	0·556*	0·507, 0·605	0·628***	0·587, 0·670	0·600***	0·553, 0·647
ABSI	0·511	0·468, 0·554	0·525	0·475, 0·574	0·511	0·467, 0·556	0·532	0·484, 0·579
Females								
WHtR	0·619***	0·575, 0·663	0·619***	0·559, 0·680	0·639***	0·584, 0·695	0·590***	0·551, 0·629
BRI	0·618***	0·574, 0·662	0·614***	0·553, 0·676	0·638***	0·582, 0·694	0·590***	0·551, 0·630
ABSI	0·597***	0·552, 0·642	0·558	0·497, 0·620	0·557	0·494, 0·621	0·495	0·454, 0·536

BP, blood pressure; HDL-C, HDL cholesterol; WHtR, waist-to-height ratio; BRI, body roundness index; ABSI, a body shape index.
$^*P<0·05$, $^{***}P<0·001$.

Table 5 Area under the receiver-operating characteristic curve (AUC), and its 95 % confidence interval, for each body index according to the number of cardiometabolic risk factors and gender among non-obese adults (*n* 1596) attending a voluntary health check-up in Beijing, China, July–December 2015

	≥1 risk factor		≥2 risk factors		≥3 risk factors	
	AUC	95 % CI	AUC	95 % CI	AUC	95 % CI
Males						
WHtR	0·653***	0·607, 0·699	0·606***	0·564, 0·648	0·658***	0·601, 0·714
BRI	0·656***	0·610, 0·702	0·609***	0·567, 0·650	0·661***	0·605, 0·718
ABSI	0·511	0·463, 0·560	0·516	0·472, 0·559	0·557	0·497, 0·616
Females						
WHtR	0·633***	0·596, 0·669	0·626***	0·580, 0·673	0·715***	0·652, 0·778
BRI	0·633***	0·597, 0·670	0·623***	0·576, 0·670	0·711***	0·648, 0·773
ABSI	0·547*	0·509, 0·585	0·552*	0·502, 0·603	0·609*	0·524, 0·694

WHtR, waist-to-height ratio; BRI, body roundness index; ABSI, a body shape index.
$^*P<0·05$, $^{***}P<0·001$.

could hardly be used to identify any risk factor among males and females.

Moreover, according to the method described by Hanley and McNeil[38], there was no significant difference in the AUC value between BRI and WHtR for identifying any of the risk factors in both genders (in males (WHtR *v.* BRI): high BP, $z=0·0673$, $P=0·946$; dysglycaemia, $z=0·170$, $P=0·865$; high TAG, $z=0·101$, $P=0·920$; low HDL-C, $z=0·589$, $P=0·953$; and in females (WHtR *v.* BRI): high BP, $z=0·0321$, $P=0·974$; dysglycaemia, $z=0·114$, $P=0·909$; high TAG, $z=1·928$, $P=0·054$; low HDL-C, $z=1·000$, $P=0·500$).

The AUC values for discriminating the cardiometabolic risk factors (≥1, ≥2 or ≥3) by WHtR, BRI and ABSI for males and females are shown in Table 5. In males, generally, the AUC value for BRI was slightly higher than that for WHtR. Conversely, the AUC value for BRI was slightly lower than that for WHtR in females. The AUC

https://doi.org/10.1017/S1368980016003281 Published online by Cambridge University Press

Table 6 Sensitivity (Sens) and specificity (Spec) of the cut-off values of the body indices for the identification of cardiometabolic risk factors according to gender among non-obese adults (*n* 1596) attending a voluntary health check-up in Beijing, China, July–December 2015

	Males					Females					
	WHtR		BRI		ABSI	WHtR		BRI		ABSI	
	Cut-off	Sens, spec	Cut-off	Sens, spec	–	Cut-off	Sens, spec	Cut-off	Sens, spec	Cut-off	Sens, spec
High BP	0·47	0·681, 0·459	2·8	0·545, 0·600	†	0·47	0·438, 0·733	2·6	0·542, 0·645	0·0742	0·589, 0·577
Dysglycaemia		†	2·7	0·774, 0·350	†	0·47	0·479, 0·717	2·7	0·511, 0·697		†
High TAG	0·47	0·747, 0·471	2·8	0·700, 0·546	†	0·47	0·475, 0·718	2·4	0·808, 0·435		†
Low HDL-C	0·47	0·534, 0·624	2·8	0·626, 0·549	†	0·46	0·725, 0·456	2·4	0·718, 0·468		†
≥1 risk factor	0·47	0·675, 0·587	2·8	0·618, 0·662	†	0·46	0·714, 0·515	2·4	0·714, 0·515	0·0742	0·498, 0·594
≥2 risk factors	0·47	0·717, 0·466	2·8	0·705, 0·503	†	0·46	0·762, 0·434	2·4	0·756, 0·445	0·0741	0·549, 0·549
≥3 risk factors	0·48	0·655, 0·617	2·9	0·690, 0·598	†	0·46	0·956, 0·417	2·5	0·867, 0·511	0·0740	0·733, 0·465

WHtR, waist-to-height ratio; BRI, body roundness index; ABSI, a body shape index; BP, blood pressure; HDL-C, HDL cholesterol.
†Data are not shown due to index's inability to significantly identify the cardiometabolic risk factor.

value was lower for ABSI than for WHtR or BRI in both genders.

The corresponding sensitivity and specificity of the cut-off values of the indices for the identification of cardiometabolic risk factors are presented in Table 6. The optimal cut-off of WHtR for detecting at least one cardiometabolic risk factor was 0·47 in males and 0·46 in females; and that of BRI was 2·8 in males and 2·4 in females.

Discussion

To the best of our knowledge, the present study is the first cross-sectional one specifically comparing the ability of ABSI and BRI with that of WHtR to identify cardiometabolic risk factors in Chinese adults with normal BMI and WC. It is well known that both pre-diabetes and pre-hypertension contribute to the development of CVD[39,40]. Thus, these conditions, together with diabetes, hypertension and dyslipidaemia (including high TAG and low HDL-C) were considered as the cardiometabolic risk factors in the present study.

WHtR, an anthropometric index based on WC and height, has recently been demonstrated to be a significantly more favourable screening tool for adult metabolic risk factors than BMI or WC[16]. As well, WHtR was able to effectively predict the presence of metabolic syndrome in Chinese postmenopausal women and in non-obese Asians[18–20,41]. In a Taiwanese population with normal BMI or WC, those with an elevated WHtR might have greater levels of various cardiometabolic risk factors than those with low WHtR[17]. However, these studies did not compare WHtR with either ABSI or BRI. Recently, ABSI and BRI have been reported to be significantly associated with abdominal adipose tissue and to improve predictions of body fat percentage and visceral adiposity tissue compared with the traditional metrics of BMI and WC[24,30]. Until now, limited studies have compared the ability of BRI or ABSI with that of WHtR for predicting cardiometabolic risk factors in non-obese people. Since the characteristics of metabolically healthy obese individuals and of metabolically obese but normal-weight individuals have been described[42,43], we are required to re-evaluate the value of BMI and WC in detecting cardiometabolic risk among non-obese individuals[20]. Therefore, we conducted the current study to assess the ability of ABSI and BRI to identify CVD risk factors and determined whether they are superior to WHtR among individuals with normal BMI and WC.

The ABSI, a new body index independent of height, weight and BMI, has been reported to be more predictive for premature mortality than BMI or WC[24]. One latest population-based study reported that ABSI showed a stronger association with total, cardiovascular and cancer mortality than BMI, WC and WHtR[44]. However, Maessen *et al.* found that ABSI was not a suitable measurement to identify either CVD or CVD risk factors[32]. In addition, two Chinese studies reported that compared with BMI and WC, ABSI was not a better predictor for diabetes[25,27]. Similar results were also reported in one retrospective cohort study conducted in Japanese adults. In the present study, we found that ABSI did not correlate with any metabolic variable (including SBP, DBP, TAG, HDL-C or FBG) in males and was negatively associated with SBP and TAG, but positively with HDL-C in females; the AUC value for ABSI was obviously lower than that for WHtR in identifying hypertension, dysglycaemia and dyslipidaemia among both genders, suggesting that ABSI could hardly be used to identify any cardiometabolic risk factor among non-obese Chinese adults. As suggested by two Chinese studies[25,27], these discrepant results might be due to ethnic differences or different characteristics of study samples.

The BRI, based on WC and height, is another new obesity index proposed by Thomas *et al.* to assess obesity[30]. Thomas *et al.* showed that BRI can reflect both visceral adipose tissue and body fat percentage and can improve predictions of body fat compared with the traditional indices like BMI and WC. As far as we know, only four studies have applied the BRI to identify the presence of disease. Some studies found that BRI was not superior to the traditional obesity indices (including BMI and WC) for determining the presence of diabetes and CVD as well as CVD risk factors[27,32]. However, one study reported that BRI had a superior predictive ability for identifying hyperuricaemia than BMI and similar capabilities to those of WC and WHtR in women[31]. In addition, BRI was found to be a superior measurement compared with BMI, WC and WHtR for determining the presence of left ventricular hypertrophy[33]. However, Santos *et al.* reported that BRI is limited in predicting percentage of fat mass in athletes, particularly when compared with commonly and readily available field methods like bio-impedance analysis or skinfold prediction models[45]. The results of our present study demonstrated that while BRI was able to identify cardiometabolic risk factors in non-obese individuals, it did not exhibit a significantly better predictive ability compared with WHtR. The optimal cut-off of BRI for detecting at least one cardiometabolic risk factor was 2·8 in males and 2·4 in females, and that of WHtR for detecting at least one cardiometabolic risk factor was 0·47 in males and 0·46 in females. Of interest, the cut-off value of WHtR in males was closely consistent with one previous Chinese study, while it was not in females[20].

The present study has several limitations that should be mentioned. First, ABSI is independent of height, weight and BMI, and was proposed to predict mortality hazard in a follow-up study; we employed it to identify cardiometabolic risk factors in a cross-sectional study among non-obese people, which may to some extent affect its predictive power. Second, all participants of the present study were of Chinese ethnicity, residents of Beijing and were recruited from a single hospital; therefore, it is unclear whether our results are applicable to other ethnic groups, which requires further investigation. Third, our study participants were people who underwent health check-ups, and some of them might have had diabetes before the check-ups. These people were more concerned about their health status and were more willing to receive a health check-up, which might lead to an increased number with diabetes being included in the study population. Therefore, the high prevalence of diabetes in males (9·8 %) of our study population did not represent the overall prevalence in non-obese men, which may explain the high prevalence of diabetes in males in the study. Finally, we could not provide any mechanistic explanation for our results. As well, we did not examine 2 h postprandial glucose, which may lead to the under-diagnosis of some diabetic subjects.

Conclusions

Despite these limitations, our results showed that WHtR was a simple and effective index in assessment of cardiometabolic risk factors among non-obese adults. When evaluating cardiometabolic risk factors among non-obese adults, BRI could be used as an alternative body index to WHtR, while ABSI could not.

Acknowledgements

Acknowledgements: The authors thank all of the participants and gratefully acknowledge the Medical Examination Center, Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College. *Funding:* This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. *Conflict of interest:* The authors report no financial disclosures and no conflicts of interest. The authors alone are responsible for the content and writing of the paper. *Authorship:* P.J.L. and F.M. designed the study and participated in data management. P.J.L. reviewed and revised the manuscript critically. H.P.L. was responsible for quality assurance and control. Y.N.Z. collected the data. All authors read and approved the final manuscript. *Ethics of human subject participation:* This study was approved by the Ethics Committee of Peking Union Medical College Hospital, China Academic Medical Science and Peking Union Medical College. All participants provided written informed consent before participating in the study.

References

1. Zalesin KC, Franklin BA, Miller WM *et al.* (2011) Impact of obesity on cardiovascular disease. *Med Clin North Am* **95**, 919–937.
2. Nordmann AJ, Nordmann A, Briel M *et al.* (2006) Effects of low-carbohydrate vs low-fat diets on weight loss and cardiovascular risk factors: a meta-analysis of randomized controlled trials. *Arch Intern Med* **166**, 285–293.
3. World Health Organization (1998) *Obesity. Preventing and Managing the Global Epidemic. Report on a WHO Consultation of Obesity, 3–5 June 1997. WHO/NUT/NCD/98.1.* Geneva: WHO.
4. Fox CS, Massaro JM, Hoffmann U *et al.* (2007) Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. *Circulation* **116**, 39–48.
5. Walton C, Lees B, Crook D *et al.* (1995) Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age. *Am J Med* **99**, 459–464.
6. National Institutes of Health (1998) Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults – The Evidence Report. *Obes Res* **6**, Suppl. 2, 51S–209S.
7. Nevill AM, Stewart AD, Olds T *et al.* (2006) Relationship between adiposity and body size reveals limitations of BMI. *Am J Phys Anthropol* **129**, 151–156.
8. Thomas EL, Parkinson JR, Frost GS *et al.* (2012) The missing risk: MRI and MRS phenotyping of abdominal adiposity and ectopic fat. *Obesity (Silver Spring)* **20**, 76–87.
9. Deurenberg P, Deurenberg-Yap M & Guricci S (2002) Asians are different from Caucasians and from each other in their body mass index/body fat per cent relationship. *Obes Rev* **3**, 141–146.

10. Lear SA, Toma M, Birmingham CL *et al.* (2003) Modification of the relationship between simple anthropometric indices and risk factors by ethnic background. *Metabolism* **52**, 1295–1301.
11. Brenner DR, Tepylo K, Eny KM *et al.* (2010) Comparison of body mass index and waist circumference as predictors of cardiometabolic health in a population of young Canadian adults. *Diabetol Metab Syndr* **2**, 28.
12. Pischon T, Boeing H, Hoffmann K *et al.* (2008) General and abdominal adiposity and risk of death in Europe. *N Engl J Med* **359**, 2105–2120.
13. Kuk JL & Ardern CI (2009) Influence of age on the association between various measures of obesity and all-cause mortality. *J Am Geriatr Soc* **57**, 2077–2084.
14. Seidell JC (2010) Waist circumference and waist–hip ratio in relation to all-cause mortality, cancer and sleep apnea. *Eur J Clin Nutr* **64**, 35–41.
15. Petursson H, Sigurdsson JA, Bengtsson C *et al.* (2011) Body configuration as a predictor of mortality: comparison of five anthropometric measures in a 12 year follow-up of the Norwegian HUNT 2 study. *PLoS ONE* **6**, e26621.
16. Ashwell M, Gunn P & Gibson S (2012) Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obes Rev* **13**, 275–286.
17. Li WC, Chen IC, Chang YC *et al.* (2013) Waist-to-height ratio, waist circumference, and body mass index as indices of cardiometabolic risk among 36 642 Taiwanese adults. *Eur J Nutr* **52**, 57–65.
18. Hsieh SD & Muto T (2005) The superiority of waist-to-height ratio as an anthropometric index to evaluate clustering of coronary risk factors among non-obese men and women. *Prev Med* **40**, 216–220.
19. Park YS & Kim JS (2012) Association between waist-to-height ratio and metabolic risk factors in Korean adults with normal body mass index and waist circumference. *Tohoku J Exp Med* **228**, 1–8.
20. Zhu Q, Shen F, Ye T *et al.* (2014) Waist-to-height ratio is an appropriate index for identifying cardiometabolic risk in Chinese individuals with normal body mass index and waist circumference. *J Diabetes* **6**, 527–534.
21. Donini LM, Poggiogalle E, Del Balzo V *et al.* (2013) How to estimate fat mass in overweight and obese subjects. *Int J Endocrinol* **2013**, 285680.
22. Kang SM, Yoon JW, Ahn HY *et al.* (2011) Android fat depot is more closely associated with metabolic syndrome than abdominal visceral fat in elderly people. *PLoS One* **6**, e27694.
23. Muller MJ, Lagerpusch M, Enderle J *et al.* (2012) Beyond the body mass index: tracking body composition in the pathogenesis of obesity and the metabolic syndrome. *Obes Rev* **13**, 6–13.
24. Krakauer NY & Krakauer JC (2012) A new body shape index predicts mortality hazard independently of body mass index. *PLoS One* **7**, e39504.
25. He S & Chen X (2013) Could the new body shape index predict the new onset of diabetes mellitus in the Chinese population? *PLoS One* **8**, e50573.
26. Krakauer NY & Krakauer JC (2014) Dynamic association of mortality hazard with body shape. *PLoS One* **9**, e88793.
27. Chang Y, Guo X, Chen Y *et al.* (2015) A body shape index and body roundness index: two new body indices to identify diabetes mellitus among rural populations in northeast China. *BMC Public Health* **15**, 794.
28. Cheung YB (2014) 'A Body Shape Index' in middle-age and older Indonesian population: scaling exponents and association with incident hypertension. *PLoS One* **9**, e85421.
29. Haghighatdoost F, Sarrafzadegan N, Mohammadifard N *et al.* (2014) Assessing body shape index as a risk predictor for cardiovascular diseases and metabolic syndrome among Iranian adults. *Nutrition* **30**, 636–644.
30. Thomas DM, Bredlau C, Bosy-Westphal A *et al.* (2013) Relationship between body roundness index with body fat and visceral adipose tissue emerging from a new geometrical model. *Obesity (Silver Spring)* **21**, 2264–2271.
31. Zhang N, Chang Y, Guo X *et al.* (2016) A Body Shape Index and Body Roundness Index: two new body indices for detecting association between obesity and hyperuricemia in rural area of China. *Eur J Intern Med* **29**, 32–36.
32. Maessen MF, Eijsvogels TM, Verheggen RJ *et al.* (2014) Entering a new era of body indices: the feasibility of a body shape index and body roundness index to identify cardiovascular health status. *PLoS One* **9**, e107212.
33. Chang Y, Guo X, Li T *et al.* (2016) A Body Shape Index and Body Roundness Index: two new body indices to identify left ventricular hypertrophy among rural populations in northeast China. *Heart Lung Circ* **25**, 358–364.
34. Chobanian AV, Bakris GL, Black HR *et al.*; National Heart, Lung, and Blood Institute Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure; National High Blood Pressure Education Program Coordinating Committee (2003) The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report. *JAMA* **289**, 2560–2572.
35. Donahua RP, Stranges S, Reiman K *et al.* (2007) Elevated cystatin C concentration and progression to pre-diabetes: the Western New York study. *Diabetes Care* **30**, 1724–1729.
36. Genuth S, Alberti KG, Bennett P *et al.* (2003) Follow-up report on the diagnosis of diabetes mellitus. *Diabetes Care* **26**, 3160–3167.
37. Grundy SM, Cleeman JI, Daniels SR *et al.* (2005) Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation* **112**, 2735–2752.
38. Hanley JA & McNeil BJ (1983) A method of comparing the areas under receiver operating characteristic curves derived from the same cases. *Radiology* **148**, 839–843.
39. Marini MA, Succurro E, Castaldo E *et al.* (2012) Cardiometabolic risk profiles and carotid atherosclerosis in individuals with prediabetes identified by fasting glucose, postchallenge glucose, and hemoglobin A1c criteria. *Diabetes Care* **35**, 1144–1149.
40. Yu D, Huang J, Hu D *et al.* (2009) Association between pre-hypertension and clustering of cardiovascular disease risk factors among Chinese adults. *J Cardiovasc Pharmacol* **53**, 388–400.
41. Liu PJ, Ma F, Lou HP *et al.* (2014) Utility of obesity indices in screening Chinese postmenopausal women for metabolic syndrome. *Menopause* **21**, 509–514.
42. Stefan N, Kantartzis K, Machann J *et al.* (2008) Identification and characterization of metabolically benign obesity in humans. *Arch Intern Med* **168**, 1609–1616.
43. Ruderman NB, Schneider SH & Berchtold P (1981) The 'metabolically-obese', normal-weight individual. *Am J Clin Nutr* **34**, 1617–1621.
44. Dhana K, Kavousi M, Ikram MA *et al.* (2016) Body shape index in comparison with other anthropometric measures in prediction of total and cause-specific mortality. *J Epidemiol Community Health* **70**, 90–96.
45. Santos DA, Silva AM, Matias CN *et al.* (2015) Utility of novel body indices in predicting fat mass in elite athletes. *Nutrition* **31**, 948–954.