Comparison of obesity-related parameters as predictors of high brachial-ankle pulse wave velocity in middle-aged and elderly people in China: A multicenter cross-sectional community-based study

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Abstract

Background

The association between obesity-related parameters and occurrence of high brachial-ankle pulse wave velocity (baPWV) in Chinese middle-aged (40–59 years) and elderly people (≥ 60 years) is unknown, especially when body composition indicators are compared.

Methods

A total of 3219 middle-aged and elderly subjects who were recruited from 6 community health service centers located in Hefei, Bengbu, and Chuzhou (Anhui province, Eastern China) met the inclusion criteria and had valid data. An e-health promotion system was used to collect basic health data, and baPWV and the body composition of each subject were measured. Partial correlation and binary logistic regression analyses were performed to identify associations between obesity-related parameters and high baPWV, and receiver operating characteristic (ROC) curves were analyzed to determine the optimal cutoff values and predictive capacity of high baPWV.

Results

Partial correlation coefficients (adjusted for age and mean arterial pressure) for waist-to-height ratio (WHtR) (0.101 and 0.192) and waist circumference (WC) (0.101 and 0.172) were highest in women. The partial correlation coefficient for fat tissue index (0.158) was highest in middle-aged men. WHtR combined covariates explained the largest proportion of the variance for dependent variables in model 1, model 2 (women), and model 3 (women). R^2 ranged from 0.088 to 0.216 in Model 1. The predictive capacities of these parameters were lower in men. The area under the ROC curve was higher for WHtR (0.647–0.739) than other parameters in elderly women, with optimal cutoff values of 0.52.

Conclusions

WHtR and WC may be useful for community-based screening of women as a secondary preventative measure for high baPWV. These 2 parameters can be used in conjunction with others (eg, body composition index) to predict the risk of high baPWV based on region, age, and sex.

Background

The prevalence of overweight and obesity is increasing in China in line with the global trend; in 2016, there were more than 100 million obese people, making it the top-ranking country [1]. Compared to reference populations from 1992 to 2015, overweight and obesity have increased by 17% and 9%, respectively [2]. High body weight and inadequate body fat distribution are associated with chronic diseases such as hypertension, cardiovascular disease, metabolic syndrome, and type 2 diabetes mellitus [3, 4]. Physiologic changes caused by excess body fat include activation of the sympathetic nervous system and renin-angiotensin aldosterone system as well as endothelial dysfunction, which can lead to hypertension [5]; and increased insulin resistance, hypertriglyceridemia, decreased levels of high-density lipoprotein cholesterol, and changes in leptin levels and blood pressure are directly linked to a higher risk of cardiovascular disease [6–10].

Pulse wave velocity (baPWV) has been shown to be proportional to the rigidity of the arterial wall [11] and is a marker for increased risk of progressive organ dysfunction (eg, hypertension and decreased renal function) and the prognosis of cardiovascular diseases [12] under most circumstances. However, an increase in baPWV resulting from overweight or obesity may be attributable to a higher vascular smooth muscle tone, thereby functionally stiffening the muscular arteries of the limbs due to the activation of the sympathetic nervous and renin-angiotensin aldosterone systems and the endothelial dysfunction. This increase in baPWV does not demonstrate a structural change in the stiffness of the elastic arteries, which has been shown being predictive for cardiovascular events. But the early detection of also this functional increase in baPWV may also be important and appropriate intervention might be advised. According to the Japanese Guidelines for Noninvasive Vascular Function Test (JCS2013), a brachial-ankle baPWV of 14 m/s is considered as the moderate risk threshold at which lifestyle modification is recommended. This level corresponds to a moderate Framingham risk score and represents the point at which the risk for incident hypertension is increased in normotensive individuals [13].

The first step in elucidating the relationship between obesity-related indices and pulse wave is to establish a method for evaluating these indicators. Body fat percentage and overweight have been widely studied using body mass index (BMI), which is body weight divided by the square of height (kg/m^2) [3, 14]. However, a well-known disadvantage of BMI is that it does not differentiate between fat mass (FM) and fat-free mass (FFM), and does not take fat distribution into account [4, 15]. Analysis of body composition based on bioelectric impedance is a more useful approach for measuring fat distribution (both FM and FFM) [4]. However, it remains unclear whether BMI or body composition index is the best predictor of vascular elasticity. Another disadvantage of BMI is that it is not closely related to abdominal obesity, which better reflects visceral obesity status. Abdominal fat—i.e., surrounding the heart, liver, and kidneys—is as pathogenic as overall obesity, but is associated with a higher disease burden [11]. Visceral fat accumulation has adverse health effects, and increases the risk of cardiovascular disease to a greater extent than subcutaneous fat [3, 14–16]. In fact, waist-to-height ratio (WHtR) and waist circumference (WC) may be better indicators of abdominal obesity as they can be easily measured and also reflect overall obesity [4]. WHtR and WC may be superior to BMI for predicting the risk of diabetes, hypertension, dyslipidemia, metabolic syndrome, and cardiovascular diseases [15, 16], although this is controversial [10, 17, 18]. The best index for predicting the occurrence of high baPWV is unclear.

The relationship between obesity-related parameters and risk of arteriosclerosis or hypertension varies according to sex and age. Aging reduces arterial elasticity and causes biochemical and histologic changes in arteries, resulting in increased internalization of visceral fats [6, 11, 19, 20]. Fat is differentially distributed in men and women [21], with a higher prevalence of obesity in the latter.

Despite the increasing rates of obesity in China, few studies to date have examined the association between obesity-related parameters and incidence of high baPWV in Chinese adults, especially by comparing all indicators. The present study was carried out in order to identify the parameter (WC, BMI, WtHR, FFTI, FFI, and RTFFM) that best predicts high baPWV (> 14 m/s) in middle-aged (40–59 years) and elderly (≥ 60 years) residents of Anhui province, Eastern China, stratified by age and sex using a cross-sectional survey study design.

Methods

Study design

We used cross-sectional data obtained from a community-based study in order to identify factors that influence non-communicable chronic diseases and investigate the effects of health promotion through artificial intelligence. Data on anthropometric and biochemical parameters, cardiovascular function, lifestyle, disease status, family history of disease, and mental health were collected each year using an e-health promotion system.

Participants

We invited local residents to participate in the study through 6 community health service centers located in Anhui province (Hefei, Bengbu, and Chuzhou). A total of 4529 participants aged > 18 years were surveyed between June 2018 and January 2020. Exclusion criteria were age < 40 years (n = 800); ankle-brachial index > 1.4 or < 0.89; cardiovascular diseases (n = 350); insufficient data for baPWV (n = 28) or body composition analysis (n = 132). A total of 3219 subjects (1951 women and 1264 men; mean age ± SD, 61.32 ± 9.81 years) were ultimately included in the analysis. All subjects provided written, informed consent for participating in this study and they agreed that their data would be used. The protocol of this study was approved by the Ethics Committee of Bengbu Medical College (Anhui, China; no. 2018045).

Data collection

All physical examinations were performed by trained medical staff or medical postgraduate students according to standardized procedures. Participants were questioned regarding health-related behaviors including cigarette and alcohol consumption and amount of physical activity. For cigarette consumption, total smoking during the subject's lifetime was calculated based on the quantity and weekly frequency of cigarettes that were smoked; this was extended to consumption before quitting in the case of former smokers. The amounts of alcohol in one bottle of the most popular alcoholic beverages in Anhui province are as follows: beer (500 ml, 3.2% alcohol), 17.5 g; white liquor (450 ml, 42% alcohol), 210 g; and wine (750 ml, 13.5–14% alcohol), 97.5 g. Daily alcohol consumption was calculated using these values. When data for cigarette and alcohol consumption were missing, a value of zero was assigned. Subjects were questioned about the type, duration (in minutes), and frequency (per week) of physical activities in which they engaged. According to activity codes and metabolic equivalent (MET) intensities in the Compendium of Physical Activities [22], physical activity time was determined as minutes/MET/day and missing values were assigned the median value. Data on sleep disorder, kidney disease, diabetes, dietary salt preferences, and dietary fat content were collected through self-report questionnaires, and missing values were assigned a value of zero. The details related to the questionnaires were published elsewhere[23].

Anthropometric data

Anthropometric measurements including body height, weight, and WC were obtained while subjects were standing and wearing light clothing. Height was measured with steel tape, and weight was measured with a bioelectric impedance analyzer (BX-BCA-100; Institute of Intelligent Machines, Hefei, China). WC was measured above the iliac crest and below the lowest rib margin at minimum respiration using flexible leather tape as subjects were in the standing position. After obtaining the measurements, BMI and WHtR were calculated as the ratio of weight (kg) / height (m)^2 and WC (cm) / height (cm), respectively. There were no missing values in the anthropometric data.

Blood pressure measurement

Blood pressure was measured using a cardiovascular function tester (BX-CFTI-100; Institute of Intelligent Machines, Hefei, China), which has a cuff that can be automatically inflated and deflated. A second measurement was automatically performed 3 min after the first one, and the average value was recorded. Before the measurements, participants were required to relax; sit in a chair (feet on the floor with back supported) for > 10 min; avoid caffeine, exercise, and smoking for at least 30 min prior; empty their bladder; and remove all clothing covering the location of cuff placement. During the test period participants were instructed to lie on an examination bed and there was no communication between the participant and the observer. Mean arterial pressure (MAP) was calculated as DBP + 0.4PP.

Body composition measurements

Body composition parameters were measured using a bioelectric impedance analyzer. The participants refrained from eating and drinking 3 h before measurements were performed, and were instructed to remove their socks and stand on the machine; electrodes were placed on both hands and feet, and the subjects were instructed to lift both arms upright and touch the electrodes with their hands. Fat-free mass (FFM)—including lean tissue mass and total body water—were derived from the impedance data, and fat-free tissue index (FFTI; FFM / height^2), fat tissue index (FTI; FM / height^2), FFTI/FTI, and ratio of trunk fat to free mass (RTFFM; trunk FFM / trunk weight) were calculated.

Measurement of baPWV and definition of high baPWV

baPWV (m/s) was measured immediately after blood pressure (with participants instructed to remain supine on the same examination bed without talking) using an IIM-AS-100 system (Institute of Intelligent Machines), which recorded bilateral brachial and posterior tibial-artery pressure waveforms with an oscillometric method by means of cuffs placed on participants' arms and ankles. baPWV was calculated automatically for each arterial segment as the path length divided by the corresponding time interval.

High baPWV was defined according to the Japanese Guidelines for Noninvasive Vascular Function Test, which recommend lifestyle modifications for a baPWV value > 14 m/s on one side, as this indicates a high risk of hypertension onset in untreated normotensive individuals [13].

Statistical analysis

Data were analyzed using SPSS v23.0 software (IBM, Armonk, NY, USA). Continuous variables are expressed as mean ± SD. The Student's t test for independent samples and Pearson's chi-squared test were used to assess the significance of differences in baseline characteristics between groups according to baPWV level stratified by sex and age.

Partial correlations (adjusted for age and MAP) between obesity-related parameters and baPWV were examined. Binary logistic regression models (model 1, adjusted for age; model 2, adjusted for age and MAP; and model 3, adjusted for age, MAP, cigarette consumption, physical activity, and diabetes status) were used to examine the effects of obesity-related parameters on baPWV, with the following parameters considered as independent variables: WC, BMI, WHtR, FFTI, FTI, FFTI/FTI, and RTFFM. Standardized beta coefficient was calculated as 0.5513 × partial regression coefficient × standard deviation of independent variable as in SAS statistical software (SAS Institute, Cary, NC, USA).

Receiver operating characteristic (ROC) curves were analyzed to identify the optimal cutoff points and assess the predictive capacity of obesity-related parameters for occurrence of high baPWV by age (40–59 years and ≥ 60 years) and sex, with sensitivity and specificity values reported. Optimal cutoff points for the parameters were determined according to the largest Youden's index value (sensitivity + specificity − 1). The Z test was used to evaluate the significances between the 2 areas under the ROC curves, and Z was calculated as $(S1 - S2) / \sqrt{(SE1^2 + SE2^2)}$ (where S1 and S2 representing the areas under the ROC curve [AUC]) and SE1 and SE2 represent the corresponding standard errors), as in Stata software (StataCorp, College Station, TX, USA).

Results

Participant characteristics according to baPWV stratified by age and sex

The characteristics of the study population are presented in Table 1. The mean age of the 3219 subjects was 61.32 years (range, 40–94 years), and 61.7% (n = 1951) were women. Mean age, heart rate, SBP, and diastolic blood pressure were higher in subjects of both sexes and age categories with high baPWV value (≥ 14 m/s) as well as in those with self-reported diabetes, except in men aged ≥ 60 years (all P < 0.05). The amount of physical activity was lower in women aged ≥ 60 years with high baPWV (P < 0.05). Statistically significant differences were observed between high and low baPWV groups for WC, BMI, WHtR, FTI, and RTFFM in both age categories of women and men (≥ 60 years), and all of these values were higher in subjects with high baPWV stratified by age and sex except for RTFFM, which was lower (all *P* < 0.05).

Table 1. Baseline characteristics of the study population according to baPWV stratified by age and sex*

	Men (N=1268)						Women (N=1951)				
Age, years	40–59			≥60			40–59			≥60	
baPWV, m/s	≥14 (N=301)	<14 (N=201)	$P^{\dagger}$	≥14 (N=693)	<14 (N=73)	$P^{\dagger}$	≥14 (N=395)	<14 (N=443)	$P^{\dagger}$	≥14 (N=976)	<14 (N=13
Age, years	52.1 (5.13)	49.47 (5.6)	<0.0001	69.15 (6.04)	65.23 (4.03)	<0.0001	54.01 (4.22)	50.55 (5.55)	<0.0001	68.13 (5.58)	64.63 (3.44)
Weight, kg	72.82 (10.17)	72.66 (8.91)	0.855	70.07 (9.87)	68.49 (9.37)	0.191	62.35 (9.71)	59.31 (8.44)	<0.0001	61.28 (9)	57.66 (8.5)
Height, cm	169.94 (4.84)	170.99 (7.93)	0.066	169.12 (5.43)	169.89 (5.4)	0.249	159.61 (4.78)	160.32 (4.5)	0.029	158.11 (4.67)	158.2 (7.06)
WC, cm	89.89 (9.67)	88.39 (9.9)	0.092	91.15 (9.32)	87.78 (7.98)	0.003	86.04 (9.41)	81.55 (8.32)	<0.0001	88.63 (9.85)	82.65 (8.4)
BMI	25.21 (3.31)	25.09 (6)	0.771	24.48 (3.05)	23.72 (2.97)	0.043	24.45 (3.5)	23.05 (2.89)	<0.0001	24.5 (3.37)	23.12 (4.23)
WHtR	0.53 (0.06)	0.52 (0.07)	0.055	0.54 (0.05)	0.52 (0.05)	0.001	0.54 (0.06)	0.51 (0.05)	<0.0001	0.56 (0.06)	0.52 (0.07)
FFTI	19.92 (1.65)	19.8 (1.95)	0.458	19.43 (1.64)	19.15 (1.53)	0.158	16.44 (1.14)	16.02 (1.05)	<0.0001	16.4 (1.06)	15.98 (0.96)
FTI	5.25 (1.79)	5.31 (4.34)	0.828	5.11 (1.78)	4.55 (1.66)	0.01	8.03 (2.54)	7.03 (2.03)	<0.0001	8.16 (2.49)	7.17 (3.53)
FFTI/FTI	4.35 (2.13)	4.25 (1.43)	0.567	2.80 (1.65)	5.56 (0.6)	0.588	2.26 (0.84)	2.44 (0.62)	<0.0001	2.2 (0.73)	2.52 (0.84)
RTFFM	0.79 (0.06)	0.8 (0.06)	0.793	0.78 (0.06)	0.83 (0.07)	0.009	0.70 (0.07)	0.72 (0.06)	<0.0001	0.69 (0.07)	0.72 (0.08)
Heart rate, bp/min	72.83 (10.72)	68.74 (8.79)	<0.0001	69.65 (10.59)	65.76 (9.77)	0.003	71.06 (9.11)	68.22 (8.39)	<0.0001	69.81 (9.31)	66.02 (8.31)
SBP, mmHg	128.48 (14.27)	118.69 (10.78)	<0.0001	129.87 (15.39)	113.77 (10.14)	<0.0001	125.02 (15.43)	111.11 (11.58)	<0.0001	129.56 (15.77)	111.1 (11.38
DBP, mmHg	82.4 (9.68)	75.32 (8.38)	<0.0001	76.14 (9.15)	69.8 (6.72)	<0.0001	77.25 (10.02)	69.53 (8.35)	<0.0001	73.55 (8.64)	66.1 (7.55)
MAP, mmHg	102.25 (11.73)	93.58 (9.26)	<0.0001	101.41 (11.27)	89.84 (8.53)	<0.0001	97.68 (12.63)	87.11 (9.44)	<0.0001	99.62 (11.39)	86.53 (8.41)
Cigarette consumption, cigarettes/lifetime	52858.31 (5511.49)	47588.01 (6163.35)	0.532	62553 (4498.19)	104970 (19632.32)	0.006	1012.76 (547.65)	1239.19 (575.15)	0.777	3085.3 (1405.6)	2770. (1916.
Alcohol consumption, g/day	9.26 (22.27)	12.75 (37.56)	0.193	7.2 (21.34)	8.92 (16.99)	0.508	0.44 (4.66)	0.32 (2.79)	0.640	0.5 (4.12)	0.61 (4.17)
Physical activity time, min/MET/day	242.68 (152.47)	152.47 (181.41)	0.316	231.79 (154.87)	258.87 (177.22)	0.162	243.26 (160.30)	255.8 (180.69)	0.291	220.41 (130.83)	251.2 (136.0
Sedentary time, min/day	69.87 (8.70)	74.42 (7.82)	0.619	44.01 (3.12)	43.08 (8.03)	0.925	41.48 (4.48)	47.09 (3.67)	0.330	35.65 (2.26)	27.42 (4.66)
Sleep disorder, n	19 (6.3)	9 (4.5)	0.380	72 (10.4)	8 (11)	0.880	56 (14.2)	40 (9)	0.02	182 (18.6)	22 (16.1)
Kidney disease, n (%)	2 (0.7)	0 (0)	0.359	5 (0.7)	1 (1.4)	0.453	5 (1.3)	1 (0.2)	0.084	7 (0.7)	1 (0.7)
Diabetes, n (%)	31 (10.3)	15 (7.5)	0.179	134 (19.3)	3 (4.1)	<0.0001	39 (9.9)	12 (2.7)	<0.0001	144 (12.8)	4 (2.9)
Dietary salt preference, n (%)			0.480			0.260			0.123		
Light	89 (29.6)	54 (26.9)		282 (40.7)	30 (41.1)		162 (41)	189 (42.7)		448 (45.9)	67 (48.9)

Moderate	99 (32.9)	73 (36.3)		231 (33.3)	22 (30.1)		128 (32.4)	146 (33)		290 (29.7)	37 (27)
Salty	72 (23.9)	54 (26.9)		143 (20.6)	13 (17.8)		82 (20.8)	69 (15.6)		177 (18.1)	24 (17.5)
Dietary fat preference, n (%)			0.205			0.201			0.144		
Light	84 (27.9)	47 (23.4)		308 (44.4)	34 (46.6)		163 (41.3)	191 (43.1)		481 (49.3)	64 (46.7)
Moderate	121 (40.2)	85 (42.3)		261 (37.7)	22 (30.1)		163 (41.3)	177 (40)		348 (35.7)	52 (38)
Oily	55 (18.3)	49 (24.4)		87 (12.6)	9 (12.3)		46 (11.6)	36 (8.1)		86 (8.8)	12 (8.8)

*Continuous variables are presented as mean (standard deviation), and discontinuous variables are presented as a number followed by percentage value.

† *P* values for the difference between high and low baPWV groups stratified by sex and age were determined with the t test and Chi-squared test.

Abbreviations: baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; DBP, diastolic blood pressure; FFTI, fat-free tissue index; FTI, fat tissue index; MAP, mean arterial pressure; MET, metabolic equivalent; RTFFM, ratio of trunk fat-free mass; SBP, systolic blood pressure; WC, waist circumference; WHtR, waist-to-height ratio.

Partial correlations between obesity-related parameters and baPWV

Partial correlations (adjusted for age and MAP) between obesity-related parameters and baPWV are shown in Fig. 1. WC and WHtR were positively correlated with baPWV in women (both age groups); BMI and FTI were positively correlated in the 40–59-year age group whereas FFTI, FFTI/FTI, and RTFFM were negatively correlated. The range of partial correlation coefficients of obesity-related parameters for the 4 groups were as follows: WC, 0.039 to 0.173; BMI, − 0.023 to 0.172; WHtR, 0.04 to 0.193; FFTI, − 0.088 to 0.075; FTI, − 0.028 to 0.158; FFTI/FTI, − 0.042 to 0.042; and RTFFM, − 0.141 to 0.021. The partial correlation coefficients for WHtR and WC were highest in women while the coefficients for FTI were highest in men aged 40–59 years, with BMI and RTFFM ranking second in the same group.

Regression analyses

Associations between all obesity-related parameters and high baPWV value were significant after adjusting for age in both groups of women, but in 40–59-year-old men, only the values for WC and WHtR were significant and in men > 60 years old, the values for all parameters were significant except RTFFM (Table 2, Model 1). After adjusting for age and MAP (Model 2), the associations remained significant for FFTI/FTI in men aged 40–59 years; meanwhile, all parameters were significantly correlated with high baPWV in the same age group of women except FFTI/FTI and RTFFM, but only WC and WHtR were significantly correlated with high baPWV. In model 3, after adjusting for age, MAP, cigarette consumption, physical activity, and diabetes status, the associations between WC and high baPWV were significant in both age groups of men, while BMI in the 40–59-year age group and FFTI/FTI in the > 60 age group of men, and WC, BMI, and FTI in both age groups of women were also significant. In all statistically significant correlations, combined covariates of WHtR explained the largest proportion of the variance for dependent variables except in model 2 in the 40–59-year age group of men and model 3 in both age groups of men; R^2 ranged from 0.088 to 0.216 (beta range, 0.0001–13.7507) in Model 1, whereas the beta of RTFFM was higher than other beta values in these 3 groups of men in Models 2 and 3.

Table 2
Association between obesity-related parameters and incidence of high brachial-ankle pulse wave velocity value, after adjusting for confounding factors*

	Model 1			**Model 2**			**Model 3**		
	R^2	Beta	*P*	R^2	Beta	*P*	R^2	Beta	*P*
Men (40–59 years)									
WC (cm)	0.084	0.0001	0.045	0.18	0.0000	0.588	0.182	0.005	0.01
BMI	0.075	0.0014	0.523	0.181	0.0007	0.267	0.185	0.042	0.034
WHtR	0.088	3.2366	0.025	0.181	1.6690	0.244	0.184	1.706	1.633
FFTI	0.077	0.0018	0.263	0.182	0.0034	0.175	0.186	−0.096	0.068
FTI	0.074	0.0001	0.861	0.181	−0.0021	0.317	0.185	−0.075	0.064
FFTI/FTI	0.074	0.0006	0.668	0.188	0.0045	0.026	0.193	0.153	0.063
RTFFM	0.074	−0.3750	0.776	0.184	3.0312	0.095	0.188	3.608	1.86
Men (≥ 60 years)									
WC (cm)	0.121	0.0004	0.003	0.142	0.0001	0.404	0.171	0.003	0.018
BMI	0.111	0.0024	0.02	0.141	−0.0008	0.568	0.172	0.063	0.054
WHtR	0.127	13.7507	0.001	0.142	5.2792	0.3	0.171	1.634	3.181
FFTI	0.109	0.0077	0.034	0.141	−0.0005	0.852	0.171	−0.053	0.098
FTI	0.115	0.0083	0.01	0.141	−0.0025	0.559	0.173	−0.126	0.095
FFTI/FTI	0.112	−0.0010	0.008	0.142	−0.0005	0.52	0.171	−0.016	0.045
RTFFM	0.108	−4.5236	0.033	0.142	2.5869	0.393	0.173	3.852	2.541
Women (40–59 years)									
WC (cm)	0.204	0.0003	< 0.0001	0.269	0.0004	< 0.0001	0.272	0.035	0.01
BMI	0.203	0.0021	< 0.0001	0.263	0.0011	0.004	0.267	0.072	0.027
WHtR	0.216	8.2725	< 0.0001	0.274	6.2477	< 0.0001	0.276	6.784	1.606
FFTI	0.199	0.0174	< 0.0001	0.264	0.0103	0.003	0.267	0.216	0.079
FTI	0.199	0.0038	< 0.0001	0.262	0.0020	0.009	0.266	0.092	0.037
FFTI/FTI	0.164	−0.0222	< 0.0001	0.256	−0.0037	0.595	0.26	−0.095	0.113
RTFFM	0.179	−3.4973	< 0.0001	0.258	−1.3702	0.118	0.262	−1.948	1.269
Women (≥ 60 years)									
WC (cm)	0.155	0.0004	< 0.0001	0.183	0.0003	0.002	0.189	0.039	0.012
BMI	0.127	0.0022	< 0.0001	0.175	0.0006	0.373	0.182	0.026	0.034
WHtR	0.146	9.1567	< 0.0001	0.181	5.6120	0.004	0.187	5.064	1.895
FFTI	0.125	0.0214	< 0.0001	0.177	0.0112	0.117	0.183	0.166	0.115
FTI	0.124	0.0036	< 0.0001	0.175	0.0006	0.563	0.182	0.021	0.045
FFTI/FTI	0.128	−0.0272	< 0.0001	0.176	−0.0097	0.283	0.182	−0.118	0.127
RTFFM	0.128	−3.8469	< 0.0001	0.175	−1.1606	0.326	0.182	−1.307	1.467

*Standardized beta coefficients are given for each measurement in Model 1 (age), Model 2 (age and MAP), and Model 3 (age, MAP, cigarette consumption, physical activity, and diabetes status). Standardized beta coefficient = 0.5513 × partial regression coefficient × standard deviation of independent variable.

BMI, body mass index; FFTI, fat-free tissue index; FTI, fat tissue index; MAP, mean arterial pressure; RTFFM, ratio of trunk fat-free mass; WC, waist circumference; WHtR, waist-to-height ratio.

Association between obesity-related parameters and high baPWV by ROC curve analysis

Table 3 shows the AUCs of WC, BMI, WHtR, FFTI, and FTI for predicting high baPWV. All of these obesity-related parameters showed a reasonable predictive capacity for high baPWV in women (all with 95% confidence interval [CI] > 0.5). However, this capacity decreased for middle-aged and elderly men (95% CI < 0.5), except in the case of WC and WHtR (95% CI > 0.5 for both groups). The discriminatory power of WHtR for high baPWV was stronger in women, and was approximately 69.3% (AUC = 0.693; 95% CI: 0.647–0.739) and 66.7% (AUC = 0.667; 95% CI: 0.631–0.704) in middle-aged and elderly women, respectively. Although the AUC for WHtR appeared higher than for other parameters in both men and women (Fig. 2), only the AUCs for WC–FFTI and WHtR–FFTI in men >

60 years; WC–BMI in women aged 40–59 years; and WC–FFTI, WHtR–BMI, WHtR–FFTI, and WHtR–FTI in women > 60 years were statistically significant ($P < 0.05$).

Table 3
Cutoff points for adiposity indices that predict the incidence of high brachial-ankle pulse wave velocity value

	Cutoff	Sensitivity (%)	Specificity (%)	*P*	AUC (95% CI)
Men (40–59 years)					
WC (cm)	95.5	0.256	0.856	0.047	0.522 (0.502–0.603)
BMI	23.86	0.691	0.398	0.131	0.54 (0.487–0.591)
WHtR	0.54	0.359	0.781	0.006	0.573 (0.522–0.623)
FFTI	19.62	0.551	0.537	0.178	0.535 (0.484–0.587)
FTI	5.48	0.449	0.672	0.16	0.537 (0.486–0.588)
Men (≥ 60 years)					
WC (cm)	88.5	0.595	0.589	0.004	0.603 (0.538–0.667)
BMI	24.01	0.569	0.589	0.05	0.57 (0.503–0.636)
WHtR	0.55	0.371	0.836	0.001	0.62 (0.557–0.683)
FFTI	19.73	0.421	0.74	0.115	0.556 (0.49–0.622)
FTI	5.6	0.378	0.808	0.022	0.581 (0.517–0.646)
Women (40–59 years)					
WC (cm)	83.5	0.628	0.614	< 0.0001	0.65 (0.613–0.687)
BMI	24.08	0.514	0.704	< 0.0001	0.63 (0.592–0.667)
WHtR	0.51	0.704	0.567	< 0.0001	0.667 (0.631–0.704)
FFTI	15.94	0.661	0.517	< 0.0001	0.611 (0.573–0.649)
FTI	7.56	0.557	0.661	< 0.0001	0.629 (0.591–0.666)
Women (≥ 60 years)					
WC (cm)	83.5	0.731	0.547	< 0.0001	0.678 (0.631–0.726)
BMI	23.57	0.576	0.657	< 0.0001	0.645 (0.596–0.694)
WHtR	0.52	0.733	0.591	< 0.0001	0.693 (0.647–0.739)
FFTI	15.99	0.651	0.577	< 0.0001	0.62 (0.571–0.67)
FTI	7.34	0.611	0.65	< 0.0001	0.648 (0.598–0.697)

AUC, area under the receiver operating characteristic curve; BMI, body mass index; FFTI, fat-free tissue index; FTI, fat tissue index; WC, waist circumference; WHtR, waist-to-height ratio.

The cutoff values of the 5 obesity-related parameters with high baPWV predictive capacity by ROC curve analysis are shown in Table 3. For middle-aged and elderly men, the optimal cutoff values for WC for predicting high baPWV were 95.5 and 88.5 cm, respectively; for women, the value was 83.5 in both age groups. The optimal cutoff values for WHtR were 0.54 in middle-aged men, 0.55 in elderly men, 0.51 in middle-aged women, and 0.52 in elderly women; and the optimal cutoff values for BMI in middle-aged and elderly women were 24.08 and 23.57, respectively.

Discussion

The results of this study demonstrate that associations between obesity-related parameters and high baPWV differed between sexes and age groups. In the 2 age groups of women, WC and WHtR showed positive associations with baPWV; in middle-aged men, BMI and FTI showed positive associations, while FFTI, FFTI/FTI, and RTFFM showed negative associations. The correlation coefficients of WHtR and WC were higher than that of other parameters. WHtR and baPWV in women showed the highest correlation in the binary logistic regression analysis adjusted for covariates. However, previous studies on the association between obesity-related parameters and baPWV, arteriosclerosis, or hypertension have reported conflicting findings. BMI showed the strongest association in adults [18] or only in one sex [10, 17, 18]. However, others have reported results similar to ours [21, 24–28], including a cohort study in which subjects in the highest quartile of WHtR were 4.51 times more likely to have hypertension [29]. A systematic review also found that WHtR was the best parameter for predicting cardiometabolic risk factors, including hypertension [30]. Notably, those results showed a significant association in both sexes while our findings in men were nonsignificant, which is consistent with a previous study [5]. Few studies have examined the relationship between body composition parameters and baPWV, with only one in the last 5 years demonstrating a positive correlation between FFMI and baPWV; nonetheless, this provides evidence for the value of FFMI as a predictor of arteriosclerosis [31].

In the present work, WHtR and WC had similarly modest capacities for predicting baPWV occurrence in men, and BMI had no predictive value. WHtR, WC, and BMI had similar predictive capacities in women of both age groups, whereas WHtR had slightly stronger predictive power in elderly women. Significant sex differences were observed, with lower predictive capacities in men, especially those who were middle-aged. In contrast, BMI or WC was shown to have predictive value for the occurrence of hypertension [17, 32–34]. There were no significant differences in the predictive capacities of WC, BMI, and WHtR between men and women [32]; and the predictive values of BMI, WC, and WHtR were found to differ significantly between men and women [5], with a better performance in the latter [35]. WHtR has also been proposed as the best predictor of baPWV or hypertension [26, 36–38].

The results of studies can vary according to whether the analysis is stratified by age or sex. BMI was shown to be more closely correlated with baPWV in younger subjects than in older ones [10]. Our study population included a large number of subjects aged > 40 years, with those > 60 years constituting the majority. Sex differences can also explain the discrepancies across reports. Because of metabolic adaptations during menopause, women are at greater risk than men for elevation of total and high low-density lipoprotein cholesterol after the age of 50, and are more likely to accumulate visceral fat [21]; thus, various indicators in women could show a strong association with baPWV or hypertension. Additionally, study design, statistical methods, or selection of variables for adjustment can influence the degree of association.

The cutoff values with the best predictive capacity for high baPWV in the present work based on sensitivity and specificity differed from those reported in studies of hypertension in Asian populations; the ranges were 82.70–85.2 for men and 77.5–83.5 for women [17, 32, 33, 36, 37]. The World Health Organization Working Group on Obesity recommends WC cutoff values of 85 cm for men and 80 cm for women, which are lower than those determined here (95.5 and 88.5 cm for middle-aged and elderly men, respectively; and 83.5 and 83.5 cm for middle-aged and elderly women, respectively). Our BMI ranges (23.86–24.01 for men and 24.08–23.57 for women) were similar to those in previous studies (22.65–24.12 for men and 23.53–27.7 for women) [17, 32, 33, 36], and the same was true for WHtR (0.54–0.55 for men and 0.51–0.52 for women in the present study vs 0.47–0.54 and 0.47–0.54, respectively, in previous reports) [17, 25, 32, 33, 36, 37, 39–41]. Notably, values obtained in a study conducted in Spain (WC, 90.5 cm; BMI, 26.6; WHtR, 0.54 for both sexes) [35] were much higher than those in Asian cohorts. Thus, different countries/regions should develop their own WC and WHtR cutoff values based on local epidemiologic status.

This study had several limitations. Firstly, it had a cross-sectional design and did not evaluate changes in the measured parameters. Secondly, the total number of participants was small, particularly the proportion of men aged 40–59. Finally, the results may not be generalizable to populations outside of Anhui.

Conclusions

In conclusion, the results of this study have implications for the health of middle-aged and elderly people in China, especially those at risk for high baPWV. We propose that WHtR and WC be used for community-based screening of women as secondary prevention of high baPWV. Moreover, using WHtR, WC in conjunction with other parameters to predict risk of high baPWV based on region, age, and sex could increase their predictive value.

Abbreviations

AUC, area under the receiver operating characteristic curve; baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; DBP, diastolic blood pressure; FFM, fat-free mass; FFTI, fat-free tissue index; FM, fat mass; FTI, fat tissue index; MAP, mean arterial pressure; MET, metabolic equivalent; ROC, receiver operating characteristic; RTFFM, ratio of trunk fat-free mass; SBP, systolic blood pressure; WC, waist circumference; WHtR, waist-to-height ratio.

Declarations

Ethics approval and consent to participate

All subjects provided written, informed consent for participating in this study and they agreed that their data would be used. The protocol of this study was approved by the Ethics Committee of Bengbu Medical College (Anhui, China; no. 2018045).

Consent for publication

Not applicable.

Availability of data and material

Not applicable.

Competing interests

The authors of this paper have no competing interests.

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Authors' contributions

TS: data analysis, manuscript drafting. ZCM: supervision, manuscript revision and editing. HX: data analysis, manuscript revision and editing. All authors have read and approved the final manuscript.

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Figures

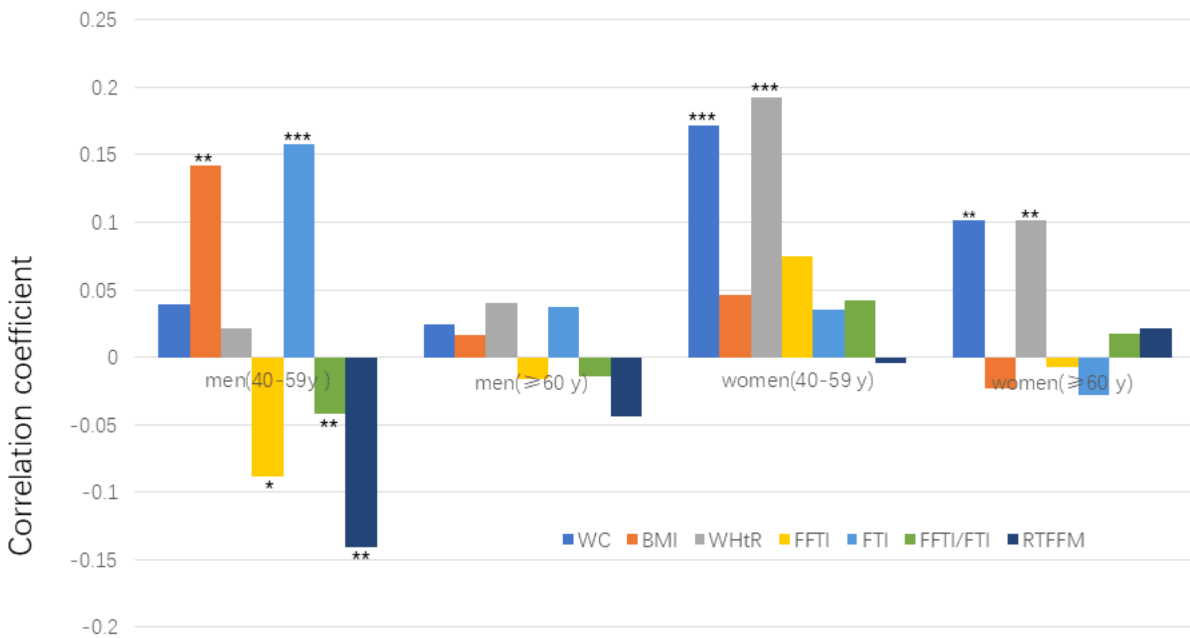

Figure 1

Partial correlation (adjusted for age and MAP) between obesity-related parameters and brachial-ankle pulse wave velocity. MAP, mean arterial pressure; WC: waist circumference, BMI body mass index; WHtR: waist—height ratio; FFTI: fat-free tissue index; FTI: fat tissue index; RTFFM: ratio of trunk fat-free mass. p<0.05,** p<0.01,*** p<0.001

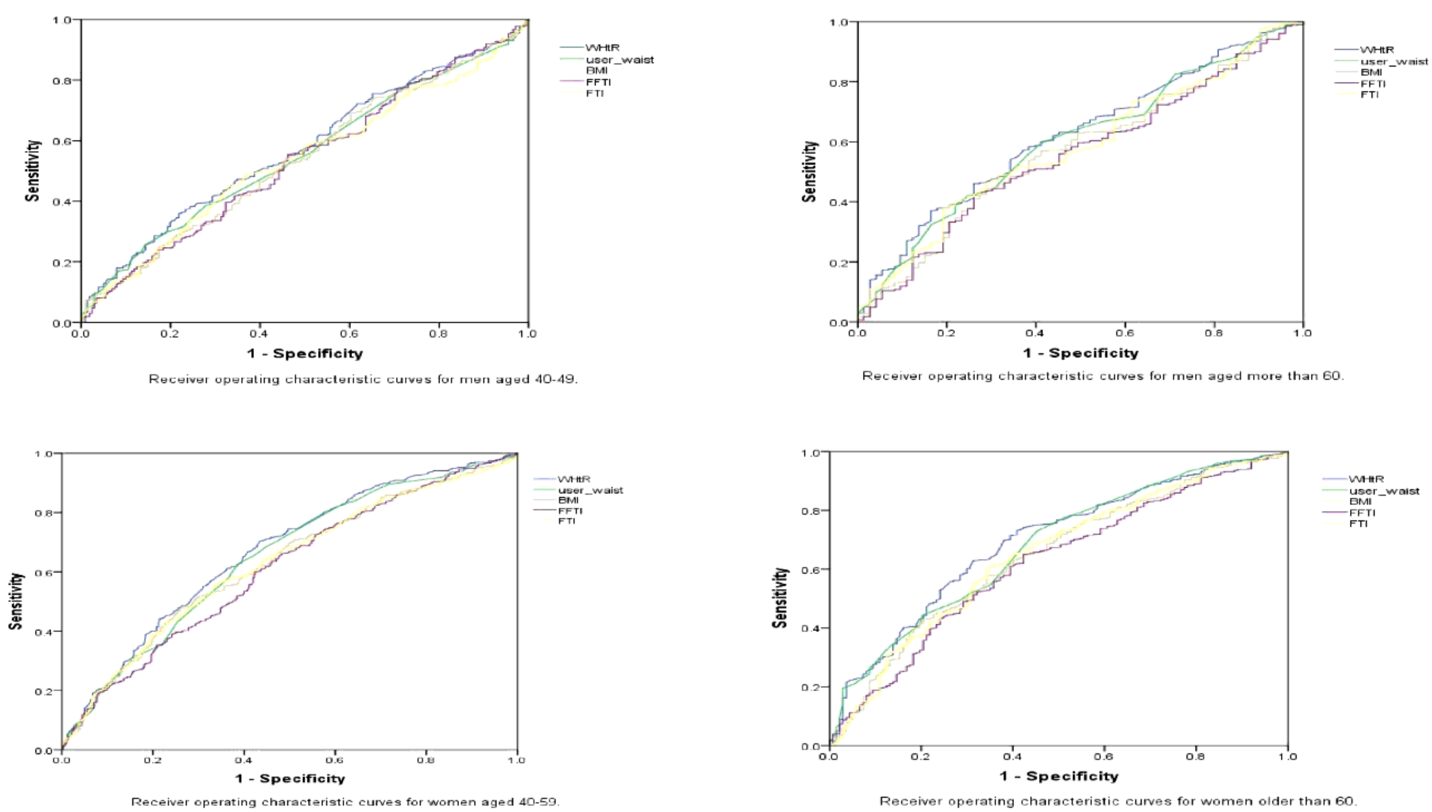

Figure 2

Receiver operating characteristic curves for incidence of arteriosclerosis risk and adiposity indices.