Analysis and Comparison of Different Obesity Evaluation Indices and Their Effects on Hypertension, Diabetes, and Dyslipidaemia

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Abstract

Background: Standard measures that define obesity and related disorders varies widely, this study investigated the relationship between different anthropometric indices of obesity criteria and their correlation to hypertension, diabetes, and dyslipidaemia in a local adult population in China.

Methods: The study participants underwent the same questionnaire survey, bio-impedance body composition analysis, and blood laboratory test. The t-test and chi-square test were used to compare the characteristics of different groups, and the receiver operating characteristic curve was used to analyse the correlation of different indicators and explore their cut-off values.

Results: The study comprised 14,926 participants, of whom 39.80% (5948/14,926) were male, and the mean age of the study population was 56.75±9.74 years. The waist circumference had the greatest influence on all factors, and BMI, AVI, and BRI were similarly correlated. WHtR had the largest AUC for predicting obesity in both sexes, and in addition, we provided a recommended cut-off value of BMI, WHR, WHtR, BAI, OBD, CI, AVI, ABSI and BRI. WHtR had the largest AUC for predicting diabetes, hypertension, and dyslipidaemia, while BMI also served as a good predictive indicator (all $P<0.001$).

Conclusions: Among the samples in this study, WHtR may be the best indicator for predicting obesity, hypertension, and dyslipidaemia, and AVI is a good indicator in Chinese adults specifically.

1. Background

Glucose and lipid metabolism are the basis of life activities and play an important role in maintaining human health. Glucose and lipid metabolism disorders can increase the risk of metabolic and cardiovascular diseases (1, 2). The prevalence of hypertension, diabetes, and dyslipidaemia in populations with obesity has greatly increased, and the global incidence of obesity-related diseases has continued to rise, posing a threat to human health (3, 4). Currently, standard measures that define obesity and related disorders varies widely. In addition to the body mass index (BMI) and waist-hip ratio, waist circumference, neck circumference, and many other measurements are used to evaluate overweight and obese populations, leading to inconsistencies in result reporting (5–7). Research shows that BMI, as an index of obesity, is more dependent on height and weight, and cannot distinguish fat from thin weight (8). The waist-to-hip ratio (WHR) is often used to determine obesity, however, a high WHR indicates abdominal fat accumulation, and does not take fat accumulation in the buttocks and limbs into account (9). BF% is used to assess obesity according to the percentage of body fat content, which determines whether an increase in body weight is due to an increase in fat or an increase in muscle and other components, serving as a more accurate measure of the degree of overall obesity (10). Therefore, this study chose BF% as the gold standard of obesity indices, to explore the consistency of other standards, and investigate the cut-off value of each indicator in Chinese adults and their relationship with obesity-related diseases, such as hypertension, diabetes, and dyslipidaemia.

2. Methods

2.1 Study design and participants

Data for this study was obtained from a population-based cohort study conducted at Ningxia Medical University between March 2018 and May 2019, comprising a random sample of more than 14,926 men and women aged 35 to 74 years. Inclusion criteria were (i) male and female adults aged between 35 and 74 (born between 1943 and 1982), (ii) registered permanent residents in the selected investigation sites (those who stay at home for more than five months throughout the year), (iii) no serious physical disability and are able to communicate normally; (iv) registration report of morbidity and death of the disease belongs to the administrator of the local health department. All participants met the above four inclusion criteria to formally participate in the study and provided written informed consent. All investigations were performed in accordance with the Declaration of Helsinki and approved by the Ethical Committee of Ningxia Medical University. The specific process is shown in Fig. 1.

2.2 Settings

All participants underwent a questionnaire interview to collect demographic data, followed by a physical examination for anthropometric variables. After blood samples were sent to the clinical laboratory testing department, biochemical measurements were performed according to standard laboratory procedures. All operations were performed by trained investigators and processed by trained and experienced laboratory technicians.

2.3 Variables

2.3.1 Demographic data

After providing informed consent, all participants were interviewed by questionnaire to obtain demographic data, such as age, sex, marital status, education status, economic status, and certain lifestyle variables, including exercise frequency, whether they smoked or not, and their alcohol, tea, spice, and vinegar consumption. Each participant was given a study ID number to ensure prevention bias.

2.3.2 Anthropometric variables

The anthropometric variables were measured by well-trained investigators. Body height (cm) was measured, in light clothing and without shoes, with a height bar. Brachial artery blood pressure and pulse were measured using an electronic sphygmomanometer. Each measurement was repeated twice; if the measured values were within 0.5 cm of one another, their average was calculated. If the difference between the two measurements exceeded 0.5 cm, then a third measurement was conducted. Weight, BMI, waist circumference, neck circumference, and other anthropometric variables were acquired using a bioelectrical impedance analyser (BIA; Inbody Co., Seoul, Korea), according to manufacturer guidelines. The BIA calculates the resistance of body tissues to an electrical signal sent through the hands and feet. Participants removed extra clothes, such as shoes, coats, sweaters, and metal accessories, such as earrings, rings, and watches, and stood on a balance scale with bare feet and grasped the handles of the BIA. The examination took approximately 30 s.

2.3.3 Biochemical variables

Blood samples were obtained between 8:00 and 10:00 am, following overnight fasting, and were used to perform biochemical analyses by means of standard laboratory enzymatic methods. These analyses included fasting blood glucose (FBG, mmol/L), total cholesterol (TC, mmol/L), triglyceride (TG, mmol/L), high-density lipoprotein cholesterol (HDL-C, mmol/L), and low-density lipoprotein cholesterol (LDL-C, mmol/L) levels. The serum was centrifuged, aliquoted, and stored at -80 °C.

2.4 Definitions

2.4.1 Definitions of obesity

Ten definitions of obesity were compared: (i) Body fat ratio (women ((Waist circumference (cm)*0.74)-(Weight (kg)*0.082 + 34.89))/Weight (kg)*100%, men ((Waist circumference (cm)*0.74)-(Weight (kg)*0.082 + 44.74))/Weight (kg)*100%, BF%); women over 30% and men over 25% were defined as obese. (ii) If the WHO definition of BMI (Weight (kg)/Height (m)^2, kg/m^2) was greater than 25.0 for Asians, they were considered obese. (iii) If the WHR (Waist circumference (cm)/ Hip circumference (cm)) was greater than 0.8 in women or 0.9 in men, it was defined as central obesity. (iv) Waist-to-height ratio (Waist circumference (cm)/ Height (cm), WHtR); a WHtR greater than 0.5 was identified as a cut-off value for obesity in this study. (v) Body adiposity index (Hip circumference (cm)/Height (m)$^{1.5}$-18), BAI). (vi) Obesity degree (standard degree=(women Height (cm)-100) *0.85, men Height (cm)-100) *0.9, OBD); participants who exceeded 20% of the standard weight were diagnosed as obese. (vii) Conicity index $((\text{Waist circumference (m)}/0.109*\sqrt{\text{Weight (kg)}/\text{Height (m)}}, \text{CI})$ (viii) Abdominal volume index ((2*Waist circumference (cm)^2+0.7*(Waist circumference (cm)- Hip circumference (cm)^2))/1000, AVI). (ix) A body shape index (Waist circumference (m)/(BMI$^{2/3}$* Height (m)$^{1/2}$), ABSI). (x) Body roundness index (364.2-365.5*(1-(Waist circumference (m)/2π/0.5* Height (m))), BRI).

2.4.2 Definitions of hypertension, diabetes, and dyslipidaemia

The diagnosis of hypertension was based on the criteria recommended by the Chinese guidelines for the treatment of hypertension in 2005, defined as systolic blood pressure ≥ 140 mmHg and diastolic blood pressure ≥ 90 mmHg. The diagnosis standard of the American Diabetes Association (ADA) in 2010 was employed, that considers a FPG ≥ 7.0 mmol/L to be an indication of diabetes. The diagnosis for dyslipidaemia refers to the 2016 (revised) guidelines for the prevention and treatment of dyslipidaemia in Chinese adults; patients with hypercholesterolaemia (TC ≥ 5.20 mmol/L), hypertriglyceridaemia (TG ≥ 1.70 mmol/L), or low-high-density lipoprotein cholesterolaemia (HDL-C < 1.00 mmol/L) were diagnosed with dyslipidaemia.

2.5 Statistical analyses

Data are presented as group mean ± standard deviation (SD) unless otherwise stated. Comparisons between males and females were performed using the t-test for continuous data and the chi-square test for categorical data. Receiver operating characteristic (ROC) analyses were then used to calculate the area under the ROC curves (AUC) between dyslipidaemia and anthropometric measures, adjusted for age and sex. All analyses were performed using SPSS statistical software version 26.0. All tests were 2-tailed, and $P < 0.05$ was considered statistically significant.

3. Results

The basic characteristics of the study population are shown in Table 1. Among the participants, 39.80% (5948/14,926) were male, the mean age of the study population was 56.75 ± 9.74 years, most of them were married (93.4%) and only had a primary school education (67.3%), and females showed less smoking and alcohol consumption, and more tea and vinegar consumption, compared to men. Males tended to have higher anthropometric measures, such as the circumference of the neck, waist, arm, and thigh (all $P < 0.001$). For the obesity criteria, BMI in this study showed no significant difference between males and females, and WHR showed little difference ($P = 0.015$). BF%, WHtR, BAI, and CI were higher in females than males, OBD, AVI, and BRI were higher in males than females, and ABSI was almost the same both groups (all $P < 0.05$). Regarding biochemical status, males tended to have higher blood pressure and FBG levels, females has higher TC, HDL-C, and LDL-C levels (all $P < 0.001$), and TG showed no statistically significant difference between the two groups.

Table 1
Characteristics of study subjects

Variables	Total (n = 14,926)	Males (n = 5948)	Females (n = 8978)	P-value
Demographic characteristics				
Age (years)	56.75 ± 9.74	58.59 ± 9.59	55.54 ± 9.69	<0.001
Marital status, n (%) Married	13,946 (93.4)	5682 (95.5)	8264 (92.0)	<0.001
Divorce/Widowed	938 (6.3)	232 (3.9)	706 (7.9)	
Unmarried	42 (0.3)	34 (0.6)	8 (0.1)	
Education, n (%) Primary school and below	10,038 (67.3)	3616 (60.7)	6422 (71.5)	<0.001
Junior high school	4323 (29.0)	2005 (34.0)	2318 (25.8)	
Senior high school and above	565 (3.7)	327 (5.3)	238 (2.7)	
Economic status (RMB/year), n (%) Less than 20,000	7927 (53.1)	3169 (53.3)	4758 (53.0)	0.349
20,000 ~ 50,000	5286 (35.4)	2074 (34.9)	3212 (35.8)	
More than 50,000	1713 (11.5)	705 (11.8)	1008 (11.2)	
Exercise(days/week), n (%) < 3	9925 (66.5)	3903 (65.6)	6022 (67.1)	0.153
3–5	1549 (10.4)	624 (10.5)	925 (10.3)	
6–7	3452 (23.1)	1421 (23.9)	2031 (22.6)	
Current Smoking (yes), n (%)	2204 (14.8)	2090 (35.1)	114(1.3)	<0.001
Alcohol consumption (yes), n (%)	3598 (24.1)	2314 (38.9)	1284 (14.3)	<0.001
Tea consumption (yes), n (%)	9007 (60.3)	4169 (70.1)	4838 (53.9)	<0.001
Spice consumption (yes), n (%)	9860 (66.1)	3896 (65.5)	5964 (66.4)	0.241
Vinegar consumption (yes), n (%)	11,317 (75.8)	4586 (77.1)	6731 (75.0)	0.003
Anthropometric variables				
SBP (mmHg)	135.37 ± 19.51	136.01 ± 19.28	134.95 ± 19.65	0.001
DBP (mmHg)	83.26 ± 12.62	84.40 ± 12.99	82.50 ± 12.31	0.001
Weight (kg)	64.01 ± 10.56	69.00 ± 10.61	60.70 ± 9.12	<0.001
Height (m)	1.60 ± 0.07	1.66 ± 0.06	1.56 ± 0.06	<0.001
NC (cm)	36.89 ± 3.04	38.43 ± 2.74	35.87 ± 2.79	<0.001
CC (cm)	93.52 ± 6.89	96.84 ± 6.66	91.31 ± 6.11	<0.001
WC (cm)	87.07 ± 9.76	88.64 ± 10.46	86.03 ± 9.11	<0.001
HC (cm)	94.40 ± 5.29	95.91 ± 5.25	93.40 ± 5.07	<0.001
LAC (cm)	31.40 ± 3.04	32.14 ± 3.09	30.91 ± 2.91	<0.001
RAC (cm)	31.38 ± 3.10	32.10 ± 3.22	30.91 ± 2.92	<0.001
LTC (cm)	48.98 ± 3.17	49.98 ± 3.18	48.31 ± 2.98	<0.001
RTC (cm)	49.30 ± 3.39	50.39 ± 3.40	48.58 ± 3.19	<0.001
Obesity criteria				
BF% (%)	31.74 ± 7.59	27.01 ± 6.57	34.87 ± 6.52	<0.001
BMI (kg/m^2)	24.94 ± 3.40	24.96 ± 3.39	24.93 ± 3.40	0.698
WHR	0.92 ± 0.06	0.92 ± 0.07	0.92 ± 0.06	0.015
WHtR	0.54 ± 0.06	0.53 ± 0.06	0.55 ± 0.06	<0.001

* P-value from two independent samples; t-test for all continuous variables and chi-square test for categorical variables.

Variables	Total (n = 14,926)	Males (n = 5948)	Females (n = 8978)	P-value
BAI	28.77 ± 3.62	26.85 ± 3.07	30.04 ± 3.39	<0.001
OBD	52.36 ± 7.93	59.58 ± 5.74	47.58 ± 5.05	<0.001
CI	1.26 ± 0.07	1.26 ± 0.07	1.27 ± 0.06	0.001
AVI	15.41 ± 3.45	16.00 ± 3.76	15.03 ± 3.16	<0.001
ABSI	0.08 ± 0.00	0.08 ± 0.00	0.08 ± 0.00	<0.001
BRI	161.07 ± 21.77	170.28 ± 22.70	154.97 ± 18.79	<0.001
Biochemical variables				
FBG (mmol/L)	5.65 ± 1.66	5.72 ± 1.74	5.60 ± 1.61	<0.001
TG (mmol/L)	1.70 ± 1.16	1.69 ± 1.23	1.71 ± 1.11	0.231
TC (mmol/L)	4.86 ± 1.05	4.71 ± 1.09	4.96 ± 1.01	<0.001
HDL-C (mmol/L)	1.35 ± 0.35	1.29 ± 0.36	1.40 ± 0.34	<0.001
LDL-C (mmol/L)	2.83 ± 0.85	2.76 ± 0.93	2.88 ± 0.80	<0.001

* P-value from two independent samples; t-test for all continuous variables and chi-square test for categorical variables.

Pearson's correlation coefficients were used to measure the correlation between obesity criteria and anthropometric and biochemical variables (Table 2). Anthropometric measures, such as weight, height, and WC, were significantly correlated with obesity criteria (all P < 0.001). Among them, BMI, AVI, and BRI have more correlation factors, and waist circumference has the most influence on all factors, notably on AVI. Hip circumference, LAC, HC, and RAC were found to correlate best with BMI, and waist circumference correlated the best with WHR, WHtR, CI, and AVI. Height and weight correlated the best with OBD and BRI. Biochemical variables have lower correlation coefficients with obesity criteria, and only blood pressure indicators showed a low correlation.

Table 2
Correlation between obesity criteria and anthropometric and biochemical variables

Variables	BF% (%)	BMI (kg/m^2)	WHR	WHtR	BAI	OBD	CI	AVI	ABSI	BRI
Weight (kg)	0.274	**0.796**	0.663	0.645	0.150	0.562	0.580	**0.883**	0.285	**0.950**
Height (m)	-0.479	-0.046	0.153	-0.187	-0.722	**0.989**	0.132	0.258	0.183	0.582
NC (cm)	0.257	**0.778**	0.710	0.687	0.208	0.463	0.629	**0.860**	0.355	**0.884**
CC (cm)	0.273	**0.836**	0.713	0.722	0.257	0.455	0.628	**0.895**	0.322	**0.915**
WC (cm)	0.592	**0.879**	**0.917**	**0.900**	0.387	0.248	**0.866**	**0.996**	0.590	**0.934**
HC (cm)	0.444	**0.918**	0.616	0.748	0.417	0.326	0.525	**0.872**	0.154	**0.853**
LAC (cm)	0.517	**0.936**	**0.763**	**0.868**	0.504	0.194	0.684	**0.925**	0.338	**0.846**
RAC (cm)	0.504	**0.914**	0.741	**0.846**	0.493	0.188	0.664	**0.900**	0.325	**0.822**
LTC (cm)	0.309	**0.801**	0.401	0.562	0.323	0.382	0.318	0.716	-0.038	0.746
RTC (cm)	0.307	**0.806**	0.392	0.561	0.333	0.374	0.306	0.713	-0.055	0.739
SBP (mmHg)	0.200	0.227	0.239	0.244	0.147	-0.013†	0.204	0.223	0.130	0.183
DBP (mmHg)	0.162	0.271	0.252	0.258	0.095	0.081	0.258	0.282	0.188	0.267
FBG (mmol/L)	0.032	0.068	0.050	0.043	-0.001†	0.035	0.064	0.063	0.055	0.065
TG (mmol/L)	0.157	0.202	0.214	0.201	0.127	0.001†	0.197	0.206	0.137	0.178
TC (mmol/L)	0.212	0.158	0.179	0.147	0.153	-0.122	0.167	0.120	0.141	0.061
HDL-C (mmol/L)	0.029*	-0.057	-0.044	-0.044	0.017*	-0.115	-0.035	-0.086	0.001†	-0.111
LDL-C (mmol/L)	0.114	0.086	0.093	0.087	0.068	-0.042	0.083	0.072	0.070	0.049

† P-value > 0.05 and shows no significant statistical difference. *P-value<0.05, and others all significant at the < 0.001 level. Measures with highest correlation coefficients for each variable in bold.

The AUC between different obesity criteria after adjusting for sex are shown in Table 3. The objective was to investigate the predictive ability of alternative obesity indices, and determine the optimal cut-off value that best balanced sensitivity and specificity, relative to the BF%. This study shows that WHtR had the largest AUC for predicting obesity in both sexes, followed by BMI and AVI, while OBD showed no significant diagnostic value. In the whole population, the sensitivity and specificity of BMI and WHtR cut-off estimation were better, while AVI was also suitable in males. The optimal cut-off value for BMI is 24.35 in men and 24.85 in women. Men have higher values for BAI, OBD, AVI, and BRI, and lower values for BMI, WHR, and WHtR compared to females, and ABSI has the same as the cut-off point of 0.08 in both sexes.

Table 3
Adjusted Area Under Receiver Operating Characteristic (ROC) Curve and cut-off points, sensitivity, and specificity between different obesity criteria

	Total (n = 14926)				**Male (n = 5948)**				**Female (n = 8978)**			
	AUC (95% CI)	**Cut-off**	**Sensitivity (%)**	**Specificity (%)**	**AUC (95% CI)**	**Cut-off**	**Sensitivity (%)**	**Specificity (%)**	**AUC (95% CI)**	**Cut-off**	**Sensitivity (%)**	**Specificity (%)**
BMI	**0.893(0.888, 0.899)**	**24.35**	**81.93**	**78.70**	**0.901(0.894, 0.909)**	24.35	79.45	83.57	**0.907(0.901, 0.914)**	24.85	78.06	82.71
WHR	**0.873(0.867, 0.879)**	0.92	75.88	78.67	**0.892(0.884, 0.900)**	0.92	75.35	85.66	**0.873(0.865, 0.881)**	0.93	69.64	81.89
WHtR	**0.947(0.944, 0.950)**	**0.54**	**79.17**	**85.30**	**0.947(0.942, 0.952)**	**0.52**	**83.26**	**89.69**	**0.945(0.941, 0.950)**	**0.55**	**85.17**	**83.99**
BAI	**0.859(0.853, 0.866)**	28.64	66.86	73.45	**0.852(0.843, 0.862)**	26.70	71.00	82.88	**0.864(0.855, 0.872)**	29.58	78.19	75.66
OBD	0.357(0.348, 0.367)	53.99	40.99	60.17	0.415(0.400, 0.430)	60.98	35.76	50.77	0.394(0.380, 0.408)	199.00	45.82	38.56
CI	**0.859(0.853, 0.865)**	1.26	72.40	77.96	**0.879(0.871, 0.888)**	1.25	75.13	83.47	0.847(0.838, 0.855)	1.26	73.89	73.98
AVI	**0.875(0.870, 0.881)**	14.79	79.49	81.02	**0.904(0.896, 0.911)**	**14.87**	**81.02**	**82.03**	**0.898(0.891, 0.905)**	14.79	77.74	80.97
ABSI	0.721(0.712, 0.730)	0.08	53.83	74.49	0.769(0.757, 0.781)	0.08	69.40	70.44	0.676(0.663, 0.689)	0.08	53.01	70.50
BRI	0.758(0.750, 0.767)	159.37	70.26	75.82	0.831(0.821, 0.841)	163.10	77.95	70.28	0.814(0.804, 0.824)	155.73	67.97	75.15

Anthropometric measures, with the highest AUC value in bold.

The AUC for each disease and the different obesity criteria are shown in Table 4. Overall, the accuracy of each obesity index in predicting hypertension, diabetes, and dyslipidaemia was not very high (all AUC < 0.7), and there was no significant difference in the use of ABSI to predict diabetes. WHtR had the largest AUC for hypertension, diabetes, and dyslipidaemia, while BMI had the same predictive level for hypertension and diabetes (all P < 0.001).

Table 4
Adjusted AUC of different obesity criteria evaluating hypertension, diabetes, and abnormal lipid metabolism

	Hypertension		Diabetes		Dyslipidaemia	
	AUC	**95% CI**	**AUC**	**95% CI**	**AUC**	**95% CI**
BR% (%)	0.600**	(0.589, 0.611)	0.571**	(0.550, 0.593)	0.600**	(0.590, 0.609)
BMI (kg/m^2)	**0.606****	**(0.595, 0.617)**	**0.573****	**(0.552, 0.594)**	0.612**	(0.603, 0.621)
WHR	0.587**	(0.576, 0.599)	0.566**	(0.545, 0.588)	0.618**	(0.609, 0.628)
WHtR	**0.606****	**(0.595, 0.617)**	**0.573****	**(0.552, 0.594)**	**0.625****	**(0.616, 0.635)**
BAI	0.582**	(0.571, 0.593)	0.544**	(0.522, 0.566)	0.576**	(0.567, 0.586)
OBD	0.475**	(0.464, 0.487)	0.491	(0.469, 0.513)	0.490*	(0.481, 0.500)
CI	0.573**	(0.561, 0.584)	0.556**	(0.535, 0.577)	0.615**	(0.606, 0.625)
AVI	0.592**	(0.581, 0.603)	0.568**	(0.547, 0.589)	0.620**	(0.611, 0.629)
ABSI	0.532**	(0.520, 0.544)	0.530**	(0.508, 0.552)	0.581**	(0.572, 0.591)
BRI	0.568**	(0.556, 0.579)	0.554**	(0.533, 0.575)	0.597**	(0.588, 0.607)

* P-value from Pearson's correlation < 0.05. ** P-value from Pearson's correlation<0.001. Obesity criteria with the highest AUC values in bold.

4. Discussion

Obesity is a chronic, non-communicable condition in which body fat accumulates excessively and impairs physical and mental health, leading to lower quality of life and shorter life expectancy (11). In recent years, with the rapid economic development and the improvement of living standards, there have been great changes in dietary structure and lifestyle habits, physical activity and exercise have reduced gradually, and the incidence of obesity is increasing and is a serious health concern (12). The prevalence of hypertension, diabetes, and dyslipidaemia is increasing significantly worldwide (13–15). The prevention and treatment of obesity-related disorders is crucial, and health concerns, such as cardiovascular disease, have increased significantly. Serious cardiovascular events and related complications have affects the physical health of patients and places a heavy burden on families and society (16). Therefore, it is very important to diagnose obesity early on, and to take preventive measures to control and reduce the adverse consequences. It is thus necessary to develop simple, effective, and reliable screening criteria for early detection. At present, there are many diagnostic criteria for obesity, but these approaches are not uniform (17, 18). The present study selected ten existing obesity criteria to explore their correlation with body measurement indicators and their cut-off values, and investigate potential relationships with hypertension, diabetes, and dyslipidaemia.

Bioelectrical impedance, as a widely used method to measure human body composition, has been recognised in many medical circles. Self-monitoring with these simple, non-invasive body measurements will help control blood pressure, blood glucose, and blood lipids, thus further preventing the occurrence of cardiovascular diseases (19). This study showed that the anthropometric measures were higher in men than in women, and BMI showed no statistical significance differences between the two groups. This may be because the BMI method to evaluate the degree of obesity in the human body is based on height and weight. It is a quality indicator that can reflect the content of fat and muscle in the body to a certain extent, but it cannot distinguish the degree of influence of fat and muscle (8). The differences in other indicators between men and women were statistically significant, suggesting that gender may be discussed in the subsequent formulation of relevant cut-off values. TG showed no significant difference between the two groups. The evaluation indices of hypertension and diabetes were higher in men than in women, while the dyslipidaemia-related indices were higher in women than in men. This may be because of the study cohort composition, that is, a rural population from Northwest China, and smoking and alcohol consumption are higher in men, which causes many related diseases (20).

Based on the correlation between obesity criteria and anthropometric and biochemical variables, waist circumference has the most influence on all factors, and some studies show that the obesity of Chinese people is mainly abdominal obesity. Related studies have pointed out that abdominal obesity is characterised by abdominal fat accumulation, which is more closely related to cardiovascular risk factors than subcutaneous adipose tissue (21). Therefore, obesity indicators should be combined with those of abdominal obesity in order to monitor the health level of the population more comprehensively. BMI, AVI, and BRI have more correlation factors, indicating that these indicators are more likely to be affected by relevant anthropometric indicators, and they are also better correlated with these indicators. Biochemical variables have low correlation coefficients with obesity criteria, suggesting that these indices are not suitable for the evaluation of obesity-related indicators (22).

BF% can accurately reflect the body fat content, distinguishing whether an increase in body mass is due to fat or muscle, which is considered the gold standard for evaluating obesity. This study showed that the BF% in females was significantly higher than males, which may be related to the differences in physiological characteristics between the different sexes. Sex hormones are important factors involved in regulating fat storage, distribution, and decomposition in the body (23). WHtR had the largest AUC for predicting obesity in both sexes, followed by BMI and AVI. WHtR has a certain evaluation effect on hypertension and abnormal lipid metabolism in the participants, while AVI had the largest AUC for diabetes, and can be used in monitoring community health. WHtR is the most suitable index for reflecting body fat distribution and central obesity. Fat accumulation in the upper body is more likely to cause diabetes and hypertension than that accumulated in the lower body. Moreover, upper body fat may directly affect fatty acids and lipid metabolism throughout the body (24, 25). Although the BF% method is considered the gold standard for determining obesity, in view of the fact that the equipment for measuring body composition is generally expensive and not suitable for handling, it is inconvenient for practical application (26). The method of WHtR determining obesity is relatively simple, and is suitable for large-scale screening of the population.

This study investigated the cut-off values of different obesity indicators, which can be used as a reference for subsequent research. In order to make the evaluation objective and accurate, it is recommended to use multiple indicators for simultaneous evaluation. The use of a combination of indices is recommended when assessing obesity, together with the fat distribution, to increase the accuracy of predicting chronic cardiovascular disease. According to the status of each obesity diagnosis index, intervention to improve physical fitness and the quality of life is important (27–29).

Several limitations exist in our study. Dyslipidaemia included any group of dyslipidaemia components, but the specific dyslipidaemia components were not grouped in this study. The results are only applicable to the preliminary screening of dyslipidaemia in the community population. The data for this study is the baseline from a cohort study and contains an inner limitation of cause-and-effect analysis. Further investigation is necessary to confirm the findings of this study.

5. Conclusions

Among the samples in this study, WHtR may be the best indicator for predicting obesity, hypertension, and dyslipidaemia, and AVI is a good indicator in Chinese adults specifically.

Abbreviations

BIA: Bioelectrical Impedance Analyser; FBG: Fasting Blood Glucose; TC: Total Cholesterol; TG: Triglyceride; HDL-C: High-Density Lipoprotein Cholesterol; LDL-C: Low-Density Lipoprotein Cholesterol; BF%: Body Fat Ratio; BMI: Body Mass Index; WHR: Waist-to-Hip Ratio; WHtR: Waist-to-Height Ratio; BAI: Body Adiposity Index; OBD: Obesity Degree; CI:Conicity Index; AVI: Abdominal Volume Index; ABSI: A Body Shape Index; BRI: Body Roundness Index; ADA: American Diabetes Association; SD: Mean ± Standard Deviation; ROC: Receiver Operating Characteristic; AUC: Area Under the ROC Curves.

Declarations

Ethics approval and consent to participate

All investigations were performed in accordance with the Declaration of Helsinki and approved by the Ethical Committee of Ningxia Medical University.

Consent for publication

All participants provided written informed consent.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available due to the data are not intended for publication but are available from the corresponding author on reasonable request.

Competing interests

The authors declared no conflicts of interest.

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Authors' contributions

Yu-hong Zhang: Conceptualization, Methodology. Yi Zhao: Data curation, Supervision. Xiao-xia Li, Xiu-ying Liu and Nan Li: Investigation. Ting Yin and Jia-xing Zhang: Formal analysis, Writing- Reviewing and Editing . All authors conducted the field investigation. All authors reviewed the manuscript.

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References

1. Han HS, Kang G, Kim JS, Choi BH, Koo SH. Regulation of glucose metabolism from a liver-centric perspective. Exp Mol Med. 2016;48:e218.
2. Kopin L, Lowenstein C. Dyslipidemia. Ann Intern Med. 2017;167(11):ITC81–96.
3. Klop B, Elte JW, Cabezas MC. Dyslipidemia in obesity: mechanisms and potential targets. Nutrients. 2013;5(4):1218–40.
4. Seravalle G, Grassi G. Obesity and hypertension. Pharmacol Res. 2017;122:1–7.
5. <Anthropometric measures of body fat and obesity-related cancer risk- sex-specific differences in Framingham Offspring Study adults.pdf>.
6. Lam BC, Koh GC, Chen C, Wong MT, Fallows SJ. Comparison of Body Mass Index (BMI), Body Adiposity Index (BAI), Waist Circumference (WC), Waist-To-Hip Ratio (WHR) and Waist-To-Height Ratio (WHtR) as predictors of cardiovascular disease risk factors in an adult population in Singapore. PLoS One. 2015;10(4):e0122985.
7. Thiebaud RS, Abe T, Loenneke JP, Fujita E, Akamine T. Body fat percentage assessment by ultrasound subcutaneous fat thickness measurements in middle-aged and older adults. Clin Nutr. 2019;38(6):2659–67.
8. Zwierzchowska A, Grabara M, Palica D, Zajac A. BMI and BAI as markers of obesity in a Caucasian population. Obes Facts. 2013;6(6):507–11.
9. Liu MM, Liu QJ, Wen J, Wang M, Wu LY, Qu ML, et al. Waist-to-hip ratio is the most relevant obesity index at each phase of insulin secretion among obese patients. J Diabetes Complications. 2018;32(7):670–6.
10. Park SK, Ryoo JH, Oh CM, Choi JM, Chung PW, Jung JY. Body fat percentage, obesity, and their relation to the incidental risk of hypertension. J Clin Hypertens (Greenwich). 2019;21(10):1496–504.
11. Gianfrancesco MA, Paquot N, Piette J, Legrand-Poels S. Lipid bilayer stress in obesity-linked inflammatory and metabolic disorders. Biochem Pharmacol. 2018;153:168–83.
12. <Effect of dietary protein content on weight gain, energy expenditure, and body composition during overeating- a randomized controlled trial..pdf>.
13. <Risk of. type 2 diabetes according to traditional and emerging anthropometric indices in Spain, a Mediterranean country with high prevalence of obesity- results from a large-scale prospective cohort study.pdf&gt.
14. Susic D, Varagic J. Obesity. A Perspective from Hypertension. Med Clin North Am. 2017;101(1):139–57.
15. Li Z, Zhang H. Reprogramming of glucose, fatty acid and amino acid metabolism for cancer progression. Cell Mol Life Sci. 2016;73(2):377–92.
16. Bastien M, Poirier P, Lemieux I, Despres JP. Overview of epidemiology and contribution of obesity to cardiovascular disease. Prog Cardiovasc Dis. 2014;56(4):369–81.
17. Lam BC, Lim SC, Wong MT, Shum E, Ho CY, Bosco JI, et al. A method comparison study to validate a novel parameter of obesity, the body adiposity index, in Chinese subjects. Obesity (Silver Spring). 2013;21(12):E634-9.
18. Savva SC, Lamnisos D, Kafatos AG. Predicting cardiometabolic risk: waist-to-height ratio or BMI. A meta-analysis. Diabetes Metab Syndr Obes. 2013;6:403–19.
19. Sergi G, De Rui M, Stubbs B, Veronese N, Manzato E. Measurement of lean body mass using bioelectrical impedance analysis: a consideration of the pros and cons. Aging Clin Exp Res. 2017;29(4):591–7.
20. Flenaugh EL. Tobacco smoking in China: a pulmonary health crisis. Curr Opin Pulm Med. 2019;25(2):188–91.
21. Cameron AJ, Magliano DJ, Shaw JE, Zimmet PZ, Carstensen B, Alberti KG, et al. The influence of hip circumference on the relationship between abdominal obesity and mortality. Int J Epidemiol. 2012;41(2):484–94.
22. Silveira EA, Pagotto V, Barbosa LS, Oliveira C, Pena GDG, Velasquez-Melendez G. Accuracy of BMI and waist circumference cut-off points to predict obesity in older adults. Cien Saude Colet. 2020;25(3):1073–82.
23. Rahman M, Berenson AB. Accuracy of current body mass index obesity classification for white, black, and Hispanic reproductive-age women. Obstet Gynecol. 2010;115(5):982–8.
24. Karpe F, Pinnick KE. Biology of upper-body and lower-body adipose tissue–link to whole-body phenotypes. Nat Rev Endocrinol. 2015;11(2):90–100.
25. Abdolahi H, Iraj B, Mirpourian M, Shariatifar B. Association of neck circumference as an indicator of upper body obesity with cardio-metabolic risk factors among first degree relatives of diabetes patients. Adv Biomed Res. 2014;3:237.
26. Salamunes ACC, Stadnik AMW, Neves EB. The effect of body fat percentage and body fat distribution on skin surface temperature with infrared thermography. J Therm Biol. 2017;66:1–9.
27. Perissiou M, Borkoles E, Kobayashi K, Polman R. The Effect of an 8 Week Prescribed Exercise and Low-Carbohydrate Diet on Cardiorespiratory Fitness, Body Composition and Cardiometabolic Risk Factors in Obese Individuals: A Randomised Controlled Trial. Nutrients. 2020;12(2).
28. Lee PF, Ho CC, Kan NW, Yeh DP, Chang YC, Li YJ, et al. The Association between Physical Fitness Performance and Abdominal Obesity Risk among Taiwanese Adults: A Cross-Sectional Study. Int J Environ Res Public Health. 2020;17(5).
29. Alomari MA, Khabour OF, Alawneh K, Alzoubi KH, Maikano AB. The importance of physical fitness for the relationship of BDNF with obesity measures in young normal-weight adults. Heliyon. 2020;6(3):e03490.

Figures

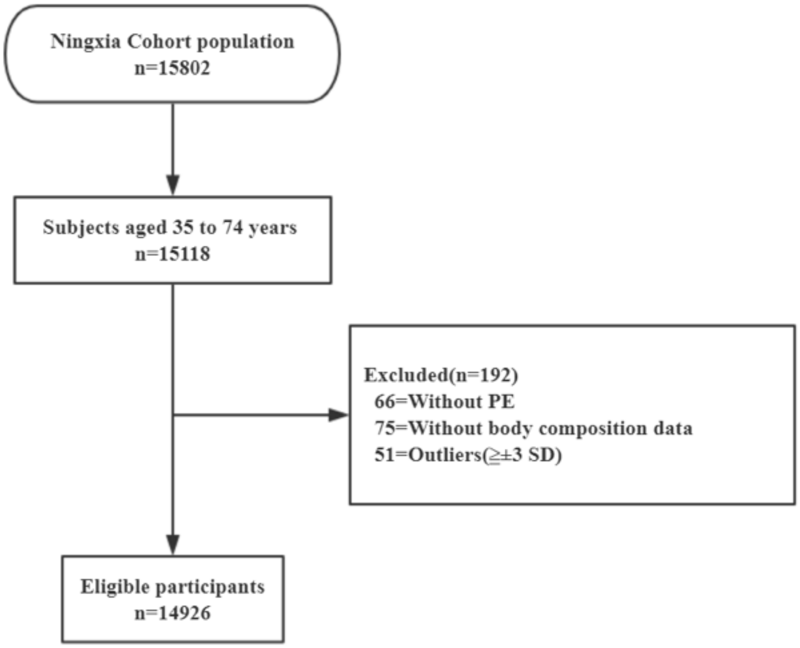

Figure 1

Respondent screening process for the participants