RESEARCH

Comparison of novel and traditional anthropometric indices in Eastern-China adults: which is the best indicator of the metabolically obese normal weight phenotype?

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Abstract

Background People with the metabolically obese normal weight (MONW) phenotype have been confirmed to significantly increase the risk of unfavorable health consequences. This study aimed to investigate the relationships between traditional and novel anthropometric indices with the MONW phenotype and compare the predictive ability of different anthropometric indices in identifying individuals with the MONW phenotype.

Methods This cross-sectional study involved a total of 26,332 participants aged 18 years or older with a normal weight from Nanjing, China. Sociodemographic information, biochemical measurements, and anthropometric indices were collected. The novel body fat anthropometric indices included body shape index (ABSI), body roundness index (BRI), abdominal volume index (AVI), weight-adjusted-waist index (WWI), body adiposity index (BAI), conicity index (CI), waist-hip-height ratio (WHHR), as well as traditional indices such as waist circumference (WC), hip circumference (HC), body mass index (BMI), waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR).The prevalence ratio (PR) from modified poisson regression and area under the receiver-operating characteristic curve (AUC) were conducted to compare the association and predictive capacity of different obesity indicators for the MONW phenotype. All analyses were stratified by sex.

Results Modified poisson regression analyses revealed that weight, WC, HC, BMI, WHR, WHtR, ABSI, BRI, AVI, WWI, BAI, CI, and WHHR were independently associated with higher risk of the MONW phenotype, regardless of whether they were treated as a continuous or categorical variable ($P < 0.05$). Notably, BRI demonstrated the strongest association in both men (highest quartile VS lowest quartile; PR = 3.14, 95%CI, 2.49, 3.96; $P < 0.001$) and women (PR = 4.63, 95%CI, 3.81, 5.62; $P < 0.001$). Receiver operating characteristic analysis indicated that AUC for the different anthropometric indices ranged from 0.50 to 0.80. BRI and WHtR had the largest AUC in both males (both AUC = 0.733; 95% CI, 0.717, 0.750) and females (both AUC = 0.773; 95% CI, 0.761, 0.786). The optimal cut-off points for BRI, determined by maximizing the Youden's index, were 3.102 (sensitivity: 63.2%, specificity: 36.2%) in males and 3.136 (sensitivity: 68.9%, specificity: 44.2%) in females. Moreover, BRI and WHtR exhibited the highest diagnostic accuracy in younger age groups, specifically those aged 18–34 in both sexes.

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Conclusions BRI emerged as the optimal predictor and independent determinant of the MONW phenotype, regardless of gender. This association was particularly pronounced in young individuals.

Keywords Metabolically obese normal weight, Anthropometric indices, Abdominal obesity, Body roundness index

Background

Obesity is primarily attributed to the excessive accumulation and storage of body fat, which can contribute to the development of various metabolic diseases and increase the risk of mortality [1, 2]. However, not all normal-weight individuals are metabolically healthy. Approximately 30% of normal-weight individuals exhibit obesity-related abnormalities, such as insulin resistance, elevated levels of triglycerides (TG), blood pressure, atherogenic lipids, and unfavorable inflammation profiles, a condition known as the metabolically obese normal weight (MONW) phenotype [3, 4]. Research indicates that MONW individuals have a higher risk of cardiovascular disease and mortality compared to overweight and abdominally obese individuals [5]. Additionally, MONW individuals face a two- to eightfold increased likelihood of developing type 2 diabetes mellitus and cardiovascular disease when compared to those with a metabolically healthy normal weight (MHNW) phenotype [6]. The presence of a normal body mass index (BMI) often conceals the need for screening in MONW individuals, leading to delayed diagnosis and treatment [7]. This issue is particularly pertinent in Asian populations, who are predisposed to visceral or abdominal obesity and an increased risk of metabolic diseases despite generally having low BMI levels [8].

The accumulation of visceral and subcutaneous fat in the abdominal region are crucial in MONW pathogenesis [4]. Traditional anthropometric indices such as waist circumference (WC), BMI, waist-to-hip ratio (WHR), and waist-to-height ratio (WHtR) are widely used for screening central obesity and identifying individuals with metabolic abnormalities [9]. However, these traditional indices have limitations in accurately discriminating between fat mass and muscle mass. BMI serves as a rough indicator of general obesity, assessing "total obesity" without considering variations in body fat distribution [10]. Whereas WC is influenced by differences in height and overall body size, making it less specific for assessing adiposity. Additionally, there remains uncertainty regarding the superiority of WHR and WHtR over WC in effectively identifying individuals at risk of cardiometabolic diseases [11, 12].

Novel indices have been developed to address these limitations. A body shape index (ABSI) was found to be related to visceral fat and carotid atherosclerosis [13]. The Body Roundness Index (BRI), which incorporates both height and WC, has been shown to reflect visceral adipose tissue and body fat percentage, demonstrating excellent predictive capacity for cardiometabolic diseases and type 2 diabetes mellitus [14–16]. The abdominal volume index (AVI) assesses overall abdominal volume and has been identified as an optimal index for identifying metabolic syndrome in non-overweight adults [17]. The conicity index (CI), which incorporates WC, height and weight, has been studied as a predictor of fasting insulin and triglyceride levels [18]. The weight-adjusted-waist index (WWI), introduced by Park et al. in 2018, has shown exceptional predictive value for cardiometabolic disease, CVD and all-cause mortality [19]. Additional indices such as the body adiposity index (BAI) and waist-hip-height ratio (WHHR) are additional unique indices that have been validated as superior predictors of body fat percentage compared to BMI [20, 21]. Despite the potential of these novel indices, there is a scarcity of studies examining their associations with the MONW phenotype in Asian populations. Furthermore, most existing studies suffer from limitations related to small sample size [11, 12, 17]. Furthermore, to date, only few studies have evaluated the predictive ability of novel markers of visceral obesity in relation to MONW individuals. Additionally, the effectiveness of these novel indices in predicting the MONW phenotype compared to traditional measures remains inconclusive.

Thus, in this study involving a large and representative sample, we aim to investigate the relationships between traditional and novel anthropometric indices with the MONW phenotype. Additionally, we evaluate the ability of novel indices to identify MONW subjects and compare them with traditional adiposity indices. Furthermore, we examine whether the discernment of traditional and novel body fat anthropometric indices is influenced by sex and age.

Methods

Study population

This population-based cross-sectional study, conducted in eastern China from January 2017 to June 2018, aimed to ascertain the prevalence of chronic diseases and associated risk factors among residents. Mandated by the National Health Commission's Bureau of Disease Control and Prevention, the Chronic Disease Center at the China CDC led the sixth nationwide chronic disease

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and risk factor survey in 2018, with Nanjing being one of the 302 selected monitoring sites. Eligible participants included all permanent residents aged 18 years or older who had lived in the local village/community for at least six months. The study required a sample size of approximately 62,000, calculated based on an estimated 10.4% prevalence of diabetes mellitus among Chinese adults aged 18 years and over. This estimation factored in a 5% margin of error, a design effect of 4, an alpha level of 0.05, and a 15% non-response rate [22]. The research utilized a multistage stratified random cluster sampling method to gather a representative regional sample. Initially, three urban districts and two rural counties were selected randomly. Subsequently, all streets within the urban districts and all townships within the rural counties were included. In the next stage, three neighborhood communities or administrative villages were selected from each street or township using probability proportionate to size (PPS). From each selected community or village, a residential group comprising at least 150 households was chosen through simple random sampling. Finally, one eligible individual per household was selected randomly using a Kish grid. The demographic composition of the survey sample closely mirrored the age and gender distribution of the permanent population in Nanjing, ensuring representativeness.

Participants in this study were required to meet the following inclusion criteria: (1) age ≥ 18 years; (2) BMI ≥ 18.5 and < 24 kg/m^2. Initially, a total of 31,787 participants were included in this cross-section study. Subsequently, individuals who met the following exclusion criteria were excluded: (1) patients with malignant tumor at baseline ($n=197$); (2) patients with myocardial infarction ($n=97$) or stroke ($n=279$) at baseline; (3) participants who had undergone a weight loss program or had lost $\geq 5\%$ of their body weight in the past 12 months ($n=4,631$); (4) individuals without anthropometric data ($n=251$). As a result, 26,332 eligible subjects (11,978 males and 14,354 females) were included in the final analysis. The inclusion and exclusion criteria for all samples are shown in Supplementary Fig. 1.

The study was approved by the academic ethics committee of Nanjing Municipal Center for Disease Control and Prevention (approval number: PJ2017-B001-01). Written informed consent was obtained from each enrolled participant.

Clinical, biochemical measurements and covariates
The standard questionnaire was designed based on the Chinese Adult Chronic Disease and Nutrition Surveillance (CACDNS) questionnaire, which is conducted every three years in China [22–24]. It includes personal basic information (age, gender, marital status, educational level, occupation type, household income, area, etc.), prevalence of behavioral risk factors (smoking, drinking, diet, physical activity), medical history, and medication history, etc. Supplementary Table 1 provides a detailed content included in the individual questionnaire. Current smokers were defined as participants who have smoked at least 100 cigarettes in their lifetime and were currently smoking [25]. Current drinker was defined as individuals who consumed at least one alcoholic beverage per week in the past month [26]. Low intake of vegetables and fruits was defined as a daily intake of less than 500 g [30]. High intake of red meat was defined as a daily intake of more than 75 g [27]. Physical activity level was measured in metabolic equivalents (MET-h/d) by considering the various types of physical activities performed by the study subjects during a typical day, along with the corresponding duration [28]. Sedentary time was defined as the duration spent sitting, leaning, or lying down (excluding sleep time) by the subjects during a typical day [29].

All participants were required to rest for at least 5 min before their blood pressure was measured. Trained personnel used Omron electronic blood pressure monitors to take three measurements on the right arm while the participants were seated, with 2-min intervals between each measurement. The final blood pressure value was obtained by averaging the last two recorded measurements. Blood samples were collected in the morning after an overnight fasting period. Fasting plasma glucose (FPG) levels was assessed using the glucose oxidase method, while total cholesterol (TC), TG, high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) were enzymatically analyzed using commercially available reagents.

Anthropometric Measurements
Anthropometric measurements, including height (cm), weight (kg), WC (cm), hip circumference (HC; cm) were conducted by trained assistants following standard protocols [30]. Height and weight were measured with participants wearing light clothing and no shoes. Height was recorded to the nearest 0.1 cm, while body weight to the nearest 0.1 kg. WC was calculated at the midaxillary line between the lowest point of the rib cage and the upper edge of iliac crest, with measurements recorded to the nearest 0.1 cm. HC was measured as the horizontal length of the hip protrusion. Using these collected parameters, various anthropometric indices such as BMI, WHR, WHtR, ABSI, BRI, AVI, WWI, BAI, CI, and WHHR were calculated using established formulas (Table 1) [11–20].

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Table 1 Formulas of anthropometric indices

Anthropometric indices	Formula
Body mass index (BMI)	$BMI = Weight_{(kg)} \div Height^2_{(m)}$
Waist-to-hip ratio (WHR)	$WHR = WC_{(cm)} \div HC_{(cm)}$
waist-to-height ratio (WHtR)	$WHtR = WC_{(cm)} \div Height_{(cm)}$
A body shape index (ABSI)	$ABSI = WC_{(m)} \div (BMI^{\frac{2}{3}} \times Height^{\frac{1}{2}}_{(m)})$
Body roundness index (BRI)	$BRI = 364.2 - 365.5 \times \sqrt{1 - (\frac{WC_{(m)}}{2\pi})^2 \div (0.5 \times Height_{(m)})^2}$
Abdominal volume index (AVI)	$AVI = \frac{2 \times WC_{(cm)}^2 + 0.7 \times (WC_{(cm)} - HC_{(cm)})^2}{1000}$
Weight-adjusted-waist-index (WWI)	$WWI = WC_{(cm)} \div Weight^{\frac{1}{2}}_{(kg)}$
Body adiposity index (BAI)	$BAI = HC_{(cm)} \div Height^{1.5}_{(m)} - 18$
Conicity index (CI)	$CI = \frac{WC_{(m)}}{0.109 \times \sqrt{\frac{Weight_{(kg)}}{Height_{(m)}}}}$
Waist-hip-height ratio (WHHR)	$WHHR = WC_{(m)} \div Height_{(m)} \div HC_{(m)}$

Abbreviations: BMI Body mass index, *WC* Waist circumference, *HC* Hip circumference, *WHR* Waist-to-hip ratio, *WHtR* Waist-to-height ratio, *ABSI* A body shape index, *BRI* Body roundness index, *AVI* Abdominal volume index, *WWI* Weight-adjusted-waist index, *BAI* Body adiposity index, *CI* Conicity index, *WHHR* Waist-hip-height ratio

Definition of metabolic phenotypes

According to the Working Group on Obesity in China criteria for Chinese [31], normal weight is defined as BMI of 18.5–23.9 kg/m^2. Metabolically abnormal traits included: (1) TG ≥ 1.7 mmol/L or lipid-lowering drugs; (2) systolic blood pressure (SBP) ≥ 130 mmHg or diastolic blood pressure (DBP) ≥ 85 mmHg or anti-hypertensive drugs; (3) FPG ≥ 5.6 mmol/L or medications for diabetes mellitus; (4) HDL-C < 1.04 mmol/L for men or < 1.30 mmol/L for women. Therefore, MONW were defined as individuals who had a normal-weight individuals who had two or more metabolically abnormal traits. MNNW was normal-weight individuals who had one or no metabolically abnormal traits [32].

Statistical analysis

Descriptive statistics for all covariates were stratified by metabolic phenotypes and summarized separately for males and females. Continuous variables were presented as means ± standard deviations (SD) or medians [interquartile ranges (IQR)], while categorical variables were reported as frequencies and percentages. Differences in characteristics among different groups were assessed using analysis of variance (ANOVA), Kruskal–Wallis test, and chi-squared (χ^2) test accordingly. Pearson's Correlation was used to explore correlation among traditional and novel anthropometric indices. The prevalence and 95% confidence intervals (CI) of the MONW phenotypes were calculated using the weight coefficients representative of the total Nanjing adult population aged ≥ 18 years [33]. The Cochran Armitage trend test was utilized to access linear trends in the proportion of the MONW phenotype across multiple anthropometric quartile variables.

The prevalence ratio (PR) and 95% CI were calculated using multivariable modified poisson regression with robust variance [34] to evaluate the independent association of sex-specific anthropometric indices with the MONW phenotype. Participants were categorized into two groups based on sex-specific cut-off points for WC, WHR and WHtR proposed by the Chinese Obesity Working Group. Weight, HC, BMI, ABSI, BRI, AVI, WWI, BAI, CI, and WHHR were then divided into sex-specific quartiles. Additionally, both traditional and novel anthropometric indices were standardized and examined as a continuous variable (per 1-SD increment) in the abovementioned model. The analyses were initially adjusted for age, education, income and area in model 1. Subsequently, adjustments were made for additional covariates including smoking, alcohol drinking, physical activity, sedentary time, intake of vegetables and fruits, and intake of red meat (model 2). Finally, further adjustments were made for hypertension, dyslipidemia, diabetes mellitus, and the use of antihypertensive, antihyperlipidemic, and antidiabetic medications (model 3).

Receiver operating characteristic (ROC) curve analyses were performed to assess the sex-specific discriminatory ability of various anthropometric indices in identifying the MONW phenotype. Additionally, we examined the diagnostic value of different anthropometric indices stratified by age. The optimal cut-off point was determined by maximizing Youden's index, which represents the maximum sum of sensitivity and specificity for each sex. Discrimination performance was measured base on the area under the ROC curve (AUC) along with its corresponding 95% CI. Pairwise comparison of AUCs among the different indices was performed using the DeLong's method [35].

Sensitivity analyses were conducted and are detailed in the supplementary materials. Subgroup ROC analyses were additionally performed to examine the ability of anthropometric indices to differentiate between premenopausal and postmenopausal status in women. To further assess the robustness of our findings, we excluded participants with baseline hypertension, dyslipidemia and diabetes mellitus. In addition, we investigated the relationship between anthropometric indicators and the MHNW phenotype, again excluding patients with hypertension, diabetes, and dyslipidemia. Additionally, we evaluated the diagnostic value of anthropometric indices for the MONW phenotype using an additional BMI

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threshold of < 23 kg/m^2 with a sample size of 20,346 individuals (42.7% male). All analyses were carried out using IBM SPSS Statistics standard 23.0 (SPSS, Inc., Chicago, USA) and the statistical software packages R version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria). All analyses were two-sided, and the difference was statistically significant at $p < 0.05$.

Results

Baseline characteristics of study participants

Of the 26,332 eligible participants, 11,978 (45.5%) were males, and the mean age was 41.26 ± 16.79 years. The prevalence of the MONW phenotype was determined to be 8.3% of males and 11.6% of females. Table 2 presents the characteristics of the study population stratified by sex and metabolic phenotypes. Irrespective of sex, MONW individuals were older than MHNW subjects. In addition, the MONW group had a higher proportion of urban residents, current smoker and drinker, as well as lower levels of education, red meat intake, and sedentary time when compared to with MHNW group ($P < 0.05$). Consistently, adults with the MONW phenotype exhibited higher SBP and DBP, as well as a higher prevalence of hypertension, dyslipidemia, diabetes mellitus, and treatment ($P < 0.001$). Regarding lipid profiles, TC, TG and LDL-C were significantly higher in both MONW females and males compared to their counterparts, while HDL-C concentrations were lower in MONW subjects (all P-values < 0.001). Furthermore, participants with the MONW phenotype had higher weight, BMI, WC, HC, WHR, WHtR, ABSI, BRI, AVI, WWI, BAI, CI, and WHHR, and lower height than those with MHNW phenotype ($P < 0.001$). The correlations matrix between traditional and novel anthropometric indicators is presented in Supplementary Table 2. All indices showed positive correlation with each other (all P-values < 0.05), except for weight and CI. Strong correlations were observed between WC, WHtR, BRI, AVI and CI in both men and women (all $r > 0.90$, P-values < 0.001). However, the linear correlation between BMI and BRI or WHtR was relatively weaker (all $r < 0.50$, P-values < 0.01).

Correlation between anthropometric indices and the MONW phenotype

As shown in Supplementary Table 3, the study subjects were categorized into four groups based on sex-specific quartiles of various anthropometric indices. In the sex-specific quartile analyses, the prevalence of the MONW phenotype exhibited a progressive increase with higher weight, BMI, WC, HC, WHR, WHtR, ABSI, BRI, AVI, WWI, BAI, CI, and WHHR quartile group among all participants. Conversely, the rates of MONW decreased across quartiles of height (p for trend < 0.001).

The sex-specific adjusted associations between anthropometric indices and the MONW phenotype are presented in Supplementary Table 4 and Supplementary Table 5. After adjusting for all confounders (model 3), multivariate modified poisson regression revealed that various anthropometric indices, including weight (males: PR = 1.25, females: PR = 1.32), WC (males: PR = 1.57, females: PR = 1.55), HC (males: PR = 1.35, females: PR = 1.38), BMI (males: PR = 1.21, females: PR = 1.39), WHR (males: PR = 1.27, females: PR = 1.28), WHtR (males: PR = 1.57, females: PR = 1.53), ABSI (males: PR = 1.35, females: PR = 1.27), BRI (males: PR = 1.51, females: PR = 1.44), AVI (males: PR = 1.49, females: PR = 1.44), WWI (males: PR = 1.47, females: PR = 1.41), BAI (males: PR = 1.32, females: PR = 1.34), CI (males: PR = 1.48, females: PR = 1.43), WHHR (males: PR = 1.19, females: PR = 1.22), were independent risk factors for the MONW phenotype (all P-values < 0.001). In addition, a significant linear trend was observed among the four weight, BMI, HC, ABSI, BRI, AVI, WWI, BAI, CI, and WHHR groups in relation to the MONW phenotype even after adjusting for multiple variables (model 3) (all P for trend < 0.001).

As depicted in Figs. 1 and 2, after adjusting for all confounders (model 3), the PR of the MONW phenotype for the highest quartile compared to the lowest quartile of novel body fat anthropometric indices showed that the indicator most strongly associated with MONW risk was BRI in both men (PR = 3.14, 95%CI, 2.49, 3.96; $P < 0.001$) and women (PR = 4.63, 95%CI, 3.81, 5.62; $P < 0.001$). Conversely, WHHR was the weakest predictor of the MONW phenotype in both sexes (men: PR = 1.45, 95%CI, 1.22, 1.71; $P < 0.001$; women: PR = 1.79, 95%CI, 1.55, 2.06; $P < 0.001$).

Predictive ability of anthropometric indices for the MONW phenotype

The sex-specific ROC analysis comparing the diagnostic performance of traditional and novel body fat anthropometric indices in identifying the MONW phenotype are provided in Table 3 and Supplementary Table 6. As outlined in Table 2, the AUC values for all anthropometric indicators range from 0.50 to 0.80 in both males and females, indicating a moderate predictive significance for the MONW phenotype. When comparing the AUC for the different indicators, BRI and WHtR exhibited the highest discriminatory capacity for detecting the MONW phenotype in both males (both AUC = 0.733; 95% CI, 0.717, 0.750) and females (both AUC = 0.773; 95% CI, 0.761, 0.786). Moreover, the optimal cut-off points for BRI, determined by maximizing the Youden's index, was 3.102 (sensitivity: 63.2%, specificity: 36.2%) in males and 3.136(sensitivity: 68.9%, specificity: 44.2%). Additionally,

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Table 2 Baseline characteristics of study participants stratified by sex and metabolic phenotypes

	Male				Female			
	Total ($n = 11,978$)	MHNW ($n = 10,982$)	MONW ($n = 996$)	*P*-value	Total ($n = 14,354$)	MHNW ($n = 12,693$)	MONW ($n = 1661$)	*P*-value	*P*-value[a]
Age (years)	41.26 ± 16.79	40.02 ± 16.38	55.01 ± 15.09	< 0.001	42.10 ± 15.36	40.26 ± 14.49	56.15 ± 14.48	0.041	< 0.001
College and higher, n (%)	6218 (51.59)	5876 (53.51)	342 (34.34)	< 0.001	7007 (48.82)	6592 (51.93)	415 (24.98)	< 0.001	< 0.001
Annual income > 30,000-yuan, n (%)	1993 (16.64)	1756 (15.99)	237 (23.80)	< 0.001	2817 (20.06)	2408 (18.97)	409 (24.63)	< 0.001	< 0.001
Urban area, n (%)	7853(65.56)	7127(64.90)	726(72.89)	< 0.001	9374(65.3%)	8137(64.1%)	1237(74.5%)	< 0.001	0.664
Current smoker, n (%)	4128 (34.46)	3697 (33.66)	431 (43.27)	< 0.001	130 (0.91)	109 (0.86)	21 (1.26)	0.007	< 0.001
Current drinker, n (%)	3801 (31.73)	3419 (31.13)	382 (38.35)	< 0.001	723 (5.04)	633 (4.99)	90 (5.42)	0.037	< 0.001
Low intake of vegetables and fruits, n (%)	6843 (57.13)	6307 (57.43)	536 (53.82)	0.027	7621 (53.09)	6733 (53.04)	888 (53.46)	0.949	< 0.001
High intake of red meat, n (%)	5943 (49.62)	5477 (49.87)	466 (45.79)	0.046	5619 (39.15)	4993 (39.34)	626 (37.69)	0.369	< 0.001
Physical activity (MET h/day)	3.00(1.14–6.00)	2.95(1.05–6.00)	3.33(1.43–6.00)	0.036	3.05(1.14–6.00)	2.86(1.14–6.00)	4.00(2.50–6.00)	< 0.001	0.469
Sedentary time (h/day)	4.50(3.00–6.50)	5.00 (3.00–7.00)	4.00(3.00–6.00)	< 0.001	4.00(3.00–6.00)	4.00(3.00–6.00)	4.00(2.50–6.00)	< 0.001	< 0.001
SBP (mmHg)	122.79 ± 16.80	121.80 ± 14.35	133.76 ± 31.54	< 0.001	118.80 ± 19.97	117.32 ± 19.52	130.05 ± 19.78	< 0.001	< 0.001
DBP (mmHg)	76.99 ± 14.35	76.45 ± 13.36	82.98 ± 21.69	< 0.001	74.47 ± 12.86	73.78 ± 10.80	79.70 ± 22.47	< 0.001	< 0.001
History of diseases, n (%)									
Hypertension	2253 (18.81)	1688 (15.37)	565 (56.73)	< 0.001	2178 (15.17)	1320(10.40)	858 (51.66)	< 0.001	< 0.001
Dyslipidemia	2624 (21.91)	1961 (17.86)	663 (66.57)	< 0.001	2992 (20.84)	2070 (16.31)	922 (55.51)	< 0.001	< 0.001
Diabetes mellitus	897 (7.49)	548 (4.99)	349 (35.04)	< 0.001	855 (5.96)	391 (3.08)	464 (27.93)	< 0.001	< 0.001
Medication, n (%)									
Anti-hypertensive drugs	1253 (10.46)	885 (8.06)	368 (36.95)	< 0.001	1274 (8.88)	669 (5.27)	605 (36.42)	< 0.001	< 0.001
Anti- hypolipidemic drugs	239 (2.00)	105 (0.96)	134 (13.45)	< 0.001	342 (2.38)	128 (1.01)	214 (12.88)	< 0.001	< 0.001
Anti-diabetic drugs	539 (4.50)	306 (2.79)	233 (23.39)	< 0.001	342 (2.38)	192 (1.51)	295 (17.76)	< 0.001	< 0.001
Laboratory examination									
FPG (mmol/L)	5.18 ± 1.50	5.05 ± 1.26	6.58 ± 2.71	< 0.001	5.07 ± 1.23	4.93 ± 1.02	6.17 ± 1.92	< 0.001	< 0.001
TC (mmol/L)	4.41 ± 1.06	4.38 ± 1.04	4.79 ± 1.27	< 0.001	4.58 ± 1.09	4.53 ± 1.06	4.92 ± 1.19	< 0.001	< 0.001
TG (mmol/L)	1.20(0.90–1.60)	1.20(0.90–1.50)	2.00(1.63–2.66)	< 0.001	1.15(0.82–1.52)	1.10(0.80–1.42)	1.80(1.33–2.32)	< 0.001	< 0.001
HDL-C (mmol/L)	1.44 ± 0.50	1.45 ± 0.49	1.30 ± 0.56	< 0.001	1.55 ± 0.52	1.57 ± 0.52	1.39 ± 0.53	< 0.001	< 0.001
LDL-C (mmol/L)	2.52 ± 0.83	2.50 ± 0.82	2.79 ± 0.89	< 0.001	2.57 ± 0.84	2.54 ± 0.82	2.86 ± 0.92	< 0.001	< 0.001
Anthropometric indices									
Height (cm)	172.4 ± 5.9	172.5 ± 5.9	171.4 ± 6.2	< 0.001	160.8 ± 5.2	161.0 ± 5.1	159.7 ± 5.5	< 0.001	< 0.001
Weight (kg)	65.3 ± 6.0	65.2 ± 6.0	66.0 ± 6.01	< 0.001	55.5 ± 5.00	55.3 ± 5.00	56.8 ± 5.00	< 0.001	< 0.001
BMI (kg/m^2)	21.94 ± 1.40	21.86 ± 1.41	22.44 ± 1.21	< 0.001	21.44 ± 1.48	21.34 ± 1.47	22.24 ± 1.29	< 0.001	< 0.001
WC (cm)	80.4 ± 7.2	79.9 ± 6.9	85.8 ± 8.4	< 0.001	75.1 ± 6.8	74.4 ± 6.4	80.6 ± 7.0	< 0.001	< 0.001
HC (cm)	92.6 ± 7.9	92.2 ± 7.70	96.4 ± 9.5	0.001	89.1 ± 7.4	88.6 ± 7.3	92.6 ± 7.7	< 0.001	< 0.001
WHR	0.87 ± 0.06	0.87 ± 0.06	0.89 ± 0.06	< 0.001	0.84 ± 0.06	0.84 ± 0.06	0.87 ± 0.06	< 0.001	< 0.001
WHtR	0.47 ± 0.04	0.46 ± 0.04	0.50 ± 0.05	< 0.001	0.47 ± 0.04	0.46 ± 0.05	0.51 ± 0.05	< 0.001	0.891
ABSI	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01	< 0.001	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	< 0.001	< 0.001
BRI	2.80 ± 0.76	2.74 ± 0.71	3.42 ± 0.92	< 0.001	2.81 ± 0.79	2.72 ± 0.73	3.50 ± 0.87	< 0.001	0.901

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Table 2 (continued)

	Male				Female			
	Total (*n* = 11,978)	MHNW (*n* = 10,982)	MONW (*n* = 996)	*P*-value	Total (*n* = 14,354)	MHNW (*n* = 12,693)	MONW (*n* = 1661)	*P*-value	*P*-value[a]
AVI	13.17 ± 2.34	13.01 ± 2.20	14.97 ± 2.96	< 0.001	11.54 ± 2.06	11.32 ± 1.92	13.22 ± 2.26	< 0.001	< 0.001
WWI	9.97 ± 0.84	9.92 ± 0.80	10.58 ± 1.01	< 0.001	10.10 ± 0.86	10.02 ± 0.82	10.72 ± 0.93	< 0.001	< 0.001
BAI	17.82 ± 3.12	17.66 ± 3.03	19.51 ± 3.60	< 0.001	18.96 ± 3.17	18.74 ± 3.08	20.68 ± 3.29	< 0.001	< 0.001
CI	1.20 ± 0.10	1.19 ± 0.09	1.27 ± 0.12	< 0.001	1.17 ± 0.10	1.17 ± 0.09	1.24 ± 0.10	< 0.001	< 0.001
WHHR	0.51 ± 0.04	0.50 ± 0.04	0.52 ± 0.04	< 0.001	0.53 ± 0.04	0.52 ± 0.04	0.55 ± 0.04	< 0.001	< 0.001

Continuous data are shown as the mean ± SDs or median (IQRs), and categorical data as n (%)

Abbreviations: *MHNW* Metabolically health normal weight, *MONW* Metabolically obese normal weight, *MET* Metabolic equivalent, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *FPG* Fasting plasma glucose, *TC* Total cholesterol, *TG* Triglycerides, *HDL-C* High-density lipoprotein cholesterol, *LDL-C* Low-density lipoprotein cholesterol, *BMI* Body mass index, *WC* Waist circumference, *HC* Hip circumference, *WHR* Waist-to-hip ratio, *WHtR* Waist-to-height ratio, *ABSI* A body shape index, *BRI* Body roundness index, *AVI* Abdominal volume index, *WWI* Weight-adjusted-waist index, *BAI* Body adiposity index, *CI* Conicity index, *WHHR* Waist-hip-height ratio

[a] *P*-value for male vs female

regardless of gender, there were no statistically significant differences between BRI and WHtR, while significant differences were observed between BRI and WC, HC, BMI, WHR, ABSI, AVI, WWI, BAI, CI and WHHR (all *P*-values < 0.001). The ability of BRI to identify the MONW phenotype was comparable to that of WHtR but significantly superior to other indices. Meanwhile, the strength of all anthropometric indicators in detection the MONW phenotype was greater in women than in men (all *P*-values < 0.05), except for ABSI (*P* = 0.926) (Supplementary Table 6).

We further assessed the diagnose accuracy of sex-specific anthropometric indices stratified by age. The AUC values of BRI and WHtR were highest among men (both AUC = 0.740; 95% CI 0.691, 0.788) and women (both AUC = 0.774; 95% CI 0.739, 0.809) aged 18–34 years (Fig. 3 and Supplementary Fig. 3). However, there was no statistically significant difference in AUC of BRI and WHtR between other age groups (except for aged ≥ 65 years) (all *P*-values > 0.05). Similar trends were observed for the remaining indicators in both sexes, except for height, weight, BMI, WHHR and WHR (Supplementary Fig. 2- Supplementary Fig. 4).

Results of the Sensitivity analyses

As shown in Supplementary Table 7, the discriminatory ability of all anthropometric indicators in the detecting

the MONW phenotype was greater in pre-menopausal women than in post-menopausal women. Additionally, AVI, BRI, WHtR, and WC showed higher diagnostic values for identifying the MONW phenotype compared to the other indices. Furthermore, the results remained consistent when we reanalyzed the data after excluding subjects with prevalent hypertension, dyslipidemia and diabetes mellitus in both males(*n* = 4,346) and females (*n* = 4,579) (Supplementary Table 8 and Supplementary Table 9). To assess the robustness of the findings, we evaluated the diagnostic value of anthropometric indices for the MONW phenotype using an additional BMI thresh-old of < 23 kg/m^2 in a sample size of 20,346 subjects (42.7% males). This analysis did not significantly alter the inverse relationship and discriminatory accuracy of all anthropometric indices (Supplementary Table 10 and Supplementary Table 11). Furthermore, we explored the relationship between anthropometric indicators and the MHNW phenotype, and found a negative correlation, which indirectly confirms the stability of our study results (Supplementary Table 12).

Discussion

To the best of our knowledge, this is the first study to systematically and comprehensively compared the diagnostic ability of novel anthropometric indices with traditional indicators in identifying and predicting the

Fig. 1 Correlation between anthropometric indices and the MONW phenotype among males (metabolically obese normal weight [MONW]; body mass index [BMI]; waist circumference [WC]; hip circumference [HC]; waist-to-hip ratio [WHR]; waist-to-height ratio [WHtR]; A body shape index [ABSI]; body roundness index [BRI]; abdominal volume index [AVI]; weight-adjusted-waist index [WWI]; body adiposity index [BAI]; conicity index [CI]; waist-hip-height ratio [WHHR]). The association was assessed by modified poisson regression analysis, adjusted by age, education, income, area, smoking, alcohol drinking, physical activity, sedentary time, intake of vegetables and fruits, intake of red meat, hypertension, dyslipidemia, diabetes, anti-hypertensive drugs, anti- hypolipidemic drugs, anti-diabetic drugs (model 3). Prevalence ratio (PR) of the anthropometric indices were represented as the squares and 95% confidence intervals (CI) by the lines through the squares
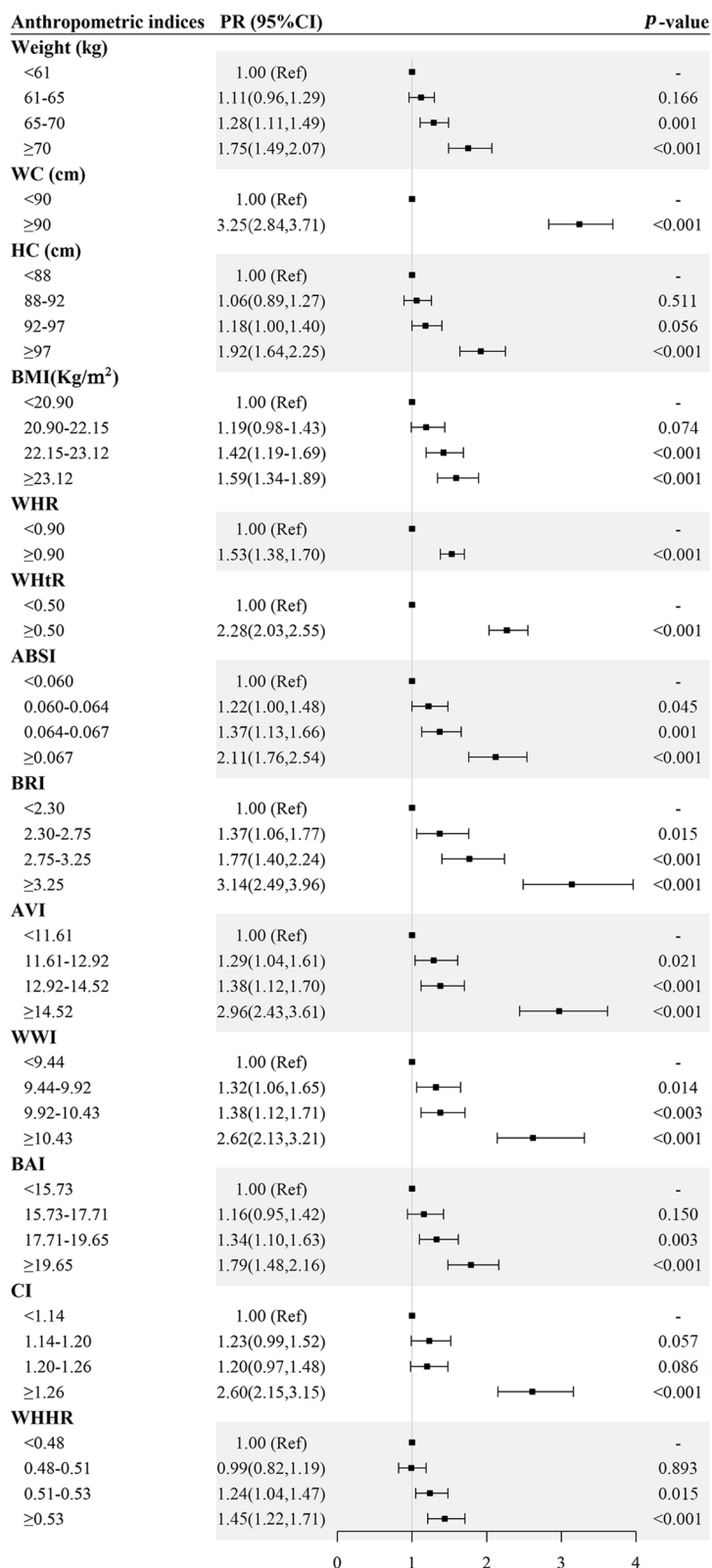
Anthropometric indices	PR (95%CI)		P-value
Weight (kg)			
<61	1.00 (Ref)		-
61-65	1.11(0.96,1.29)		0.166
65-70	1.28(1.11,1.49)		0.001
≥70	1.75(1.49,2.07)		<0.001
WC (cm)			
<90	1.00 (Ref)		-
≥90	3.25(2.84,3.71)		<0.001
HC (cm)			
<88	1.00 (Ref)		-
88-92	1.06(0.89,1.27)		0.511
92-97	1.18(1.00,1.40)		0.056
≥97	1.92(1.64,2.25)		<0.001
BMI(Kg/m^2)			
<20.90	1.00 (Ref)		-
20.90-22.15	1.19(0.98-1.43)		0.074
22.15-23.12	1.42(1.19-1.69)		<0.001
≥23.12	1.59(1.34-1.89)		<0.001
WHR			
<0.90	1.00 (Ref)		-
≥0.90	1.53(1.38,1.70)		<0.001
WHtR			
<0.50	1.00 (Ref)		-
≥0.50	2.28(2.03,2.55)		<0.001
ABSI			
<0.060	1.00 (Ref)		-
0.060-0.064	1.22(1.00,1.48)		0.045
0.064-0.067	1.37(1.13,1.66)		0.001
≥0.067	2.11(1.76,2.54)		<0.001
BRI			
<2.30	1.00 (Ref)		-
2.30-2.75	1.37(1.06,1.77)		0.015
2.75-3.25	1.77(1.40,2.24)		<0.001
≥3.25	3.14(2.49,3.96)		<0.001
AVI			
<11.61	1.00 (Ref)		-
11.61-12.92	1.29(1.04,1.61)		0.021
12.92-14.52	1.38(1.12,1.70)		<0.001
≥14.52	2.96(2.43,3.61)		<0.001
WWI			
<9.44	1.00 (Ref)		-
9.44-9.92	1.32(1.06,1.65)		0.014
9.92-10.43	1.38(1.12,1.71)		<0.003
≥10.43	2.62(2.13,3.21)		<0.001
BAI			
<15.73	1.00 (Ref)		-
15.73-17.71	1.16(0.95,1.42)		0.150
17.71-19.65	1.34(1.10,1.63)		0.003
≥19.65	1.79(1.48,2.16)		<0.001
CI			
<1.14	1.00 (Ref)		-
1.14-1.20	1.23(0.99,1.52)		0.057
1.20-1.26	1.20(0.97,1.48)		0.086
≥1.26	2.60(2.15,3.15)		<0.001
WHHR			
<0.48	1.00 (Ref)		-
0.48-0.51	0.99(0.82,1.19)		0.893
0.51-0.53	1.24(1.04,1.47)		0.015
≥0.53	1.45(1.22,1.71)		<0.001

Fig. 1 (See legend on previous page.)

MONW phenotype with a large sample size and a larger population coverage. The results highlight the positive associations between the examined traditional and novel anthropometric indices and the presence of the MONW phenotype. Among these indices, BRI emerged as the most superior screening tool and independent predictor for MONW individuals. Furthermore, BRI exhibited the highest diagnostic accuracy for the MONW phenotype in younger age groups (aged 18–34), with AUC surpassed 0.7 in both males and females.

The MONW phenotype has garnered considerable attention due to its association with cardiovascular events and adverse health outcomes [4–6]. In our study, we observed significantly higher levels of WC, WHtR and BRI in MONW participants compared to healthy individuals with normal-weight. These findings suggest that increased visceral adipose tissue, mediated by these anthropometric indices, may contribute to a worse inflammatory and metabolic profile, thereby heightening the risk of cardiovascular complications. Previous research has demonstrated that the MONW phenotype is characterized by an excess of visceral adipose tissue [4], particularly among Asian populations who exhibit a propensity for visceral fat accumulation compared to Western populations [8]. Traditional indicators such as WC, BMI, HC and WHR [9–12] have been widely used to explore the relationship between adiposity and metabolic abnormalities, cardiovascular disease and diabetes mellitus. However, the results have been inconclusive due to their limited ability to accurately reflect body fat distribution. Our study also revealed the insufficient diagnostic performance of these conventional markers. Thus, it is crucial to place greater emphasis on novel indicators that can more effectively capture excess visceral fat deposition.

BRI, a novel anthropometric index developed based on height and WC [14], has demonstrated its utility in assessing the risk of obesity-related cardiometabolic risk factors [15, 36], diabetes mellitus [37], hyperuricemia [38] and left ventricular hypertrophy [39] according to previous cross-sectional studies. Moreover, several prospective studies have shown that BRI exhibits the highest diagnostic ability in predicting diabetes mellitus [16, 40].

Aforementioned studies have consistently reported that BRI outperforms other new anthropometric indicators and traditional measures, emerging as the strongest predictor [16, 33–40], which aligns with the findings from our study. The AUC values for BRI varied between 0.630 and 0.803 in different studies [16, 36–40], potentially due to variations in outcome events, study populations, race, and diagnostic criteria. Our study adds to this body of evidence by demonstrating that BRI achieves the highest diagnostic accuracy for the MONW phenotype, with AUC values of 0.733 in males and 0.773 in females, falling within the range observed in previous studies evaluating BRI.

Interestingly, our study revealed that both BRI and WHtR demonstrated comparable predictive capability for the MONW phenotype, which were similar to the results of previous studies [17, 40]. This similarity may be attributed to the fact that both BRI and WHtR are derived from WC and height measurements. Notably, WHtR overcomes the influence of height on visceral adipose tissue by taking not only height, but also the central adiposity into account. Besides, BRI is a height-independent human body ellipse model that evaluates body fat percentage and visceral adipose tissue based on roundness and eccentricity, effectively quantifying an individual's body shape. In addition, our study found a strong positive correlation BRI and WHtR in both males and females. However, based on the preliminary analyses conducted in this study, although BRI and WHtR exhibited similar AUC values, it appears that BRI was better than WHtR based on the PR values on the association between these indices and the risk of the MONW phenotype.

Although in our analysis, the discriminatory power of AVI and WWI was found to be inferior to that of BRI, they could still be defined as "acceptable" parameters ($0.7 \leq AUC < 0.8$) based on Hosmer and Lem show standards. It is worth noting that both AVI and WWI rely on WC and abdominal fat volume measurements for the assessment of visceral adipose tissue [17, 19]. BMI is a rough index of body fat, whereas WC is a more specific indicator of visceral fat accumulation and is closely associated with metabolic abnormalities compared to BMI [36]. This may explain why AVI and WWI exhibit better

(See figure on next page.)

Fig. 2 Correlation between anthropometric indices and the MONW phenotype among females (metabolically obese normal weight [MONW]; body mass index [BMI]; waist circumference [WC]; hip circumference [HC]; waist-to-hip ratio [WHR]; waist-to-height ratio [WHtR]; A body shape index [ABSI]; body roundness index [BRI]; abdominal volume index [AVI]; weight-adjusted-waist index [WWI]; body adiposity index [BAI]; conicity index [CI]; waist-hip-height ratio [WHHR]). The association was assessed by modified poisson regression analysis, adjusted by age, education, income, area, smoking, alcohol drinking, physical activity, sedentary time, intake of vegetables and fruits, intake of red meat, hypertension, dyslipidemia, diabetes, anti-hypertensive drugs, anti-hypolipidemic drugs, anti-diabetic drugs (model 3). Prevalence ratio (PR) of the anthropometric indices were represented as the squares and 95% confidence intervals (CI) by the lines through the squares
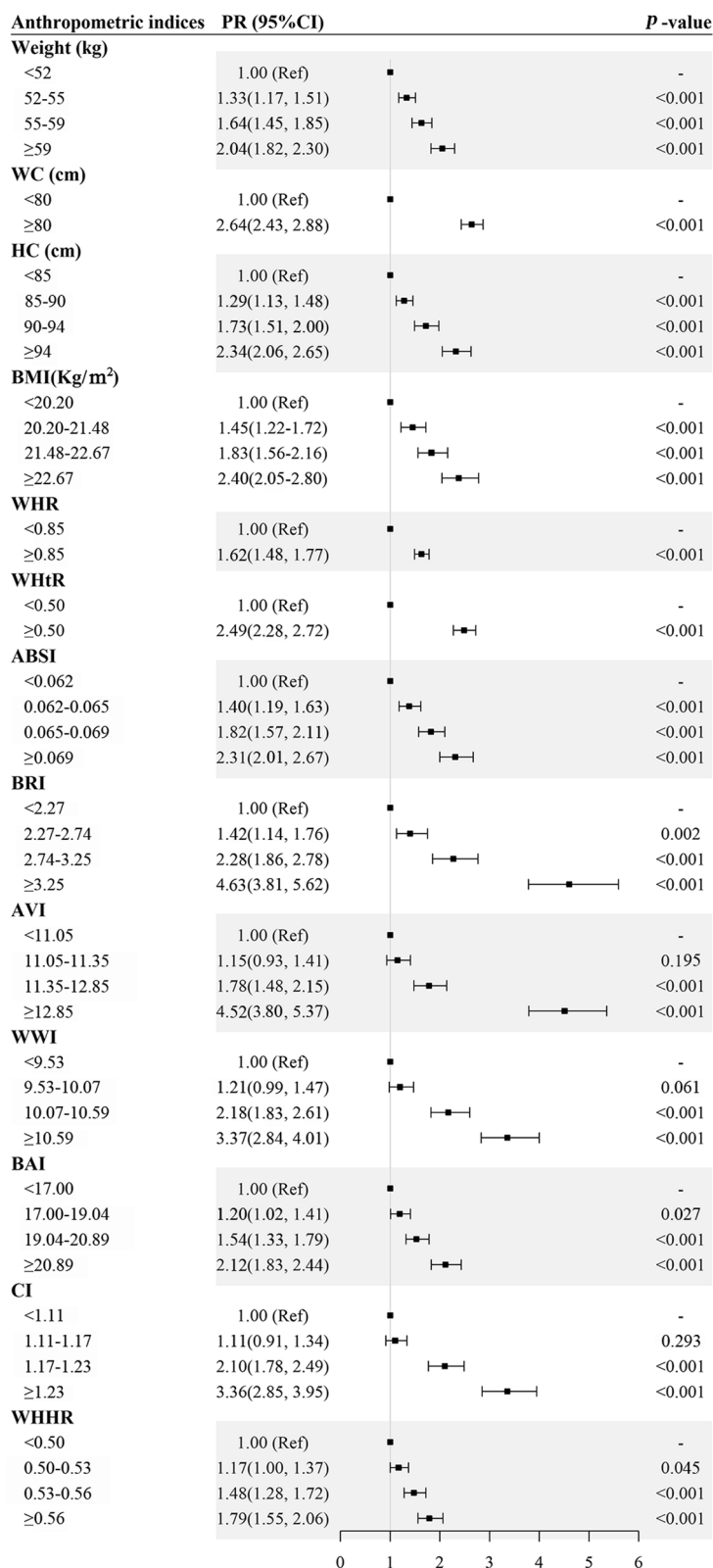
Anthropometric indices	PR (95%CI)	*P*-value
Weight (kg)		
<52	1.00 (Ref)	-
52-55	1.33(1.17, 1.51)	<0.001
55-59	1.64(1.45, 1.85)	<0.001
≥59	2.04(1.82, 2.30)	<0.001
WC (cm)		
<80	1.00 (Ref)	-
≥80	2.64(2.43, 2.88)	<0.001
HC (cm)		
<85	1.00 (Ref)	-
85-90	1.29(1.13, 1.48)	<0.001
90-94	1.73(1.51, 2.00)	<0.001
≥94	2.34(2.06, 2.65)	<0.001
BMI(Kg/m^2)		
<20.20	1.00 (Ref)	-
20.20-21.48	1.45(1.22-1.72)	<0.001
21.48-22.67	1.83(1.56-2.16)	<0.001
≥22.67	2.40(2.05-2.80)	<0.001
WHR		
<0.85	1.00 (Ref)	-
≥0.85	1.62(1.48, 1.77)	<0.001
WHtR		
<0.50	1.00 (Ref)	-
≥0.50	2.49(2.28, 2.72)	<0.001
ABSI		
<0.062	1.00 (Ref)	-
0.062-0.065	1.40(1.19, 1.63)	<0.001
0.065-0.069	1.82(1.57, 2.11)	<0.001
≥0.069	2.31(2.01, 2.67)	<0.001
BRI		
<2.27	1.00 (Ref)	-
2.27-2.74	1.42(1.14, 1.76)	0.002
2.74-3.25	2.28(1.86, 2.78)	<0.001
≥3.25	4.63(3.81, 5.62)	<0.001
AVI		
<11.05	1.00 (Ref)	-
11.05-11.35	1.15(0.93, 1.41)	0.195
11.35-12.85	1.78(1.48, 2.15)	<0.001
≥12.85	4.52(3.80, 5.37)	<0.001
WWI		
<9.53	1.00 (Ref)	-
9.53-10.07	1.21(0.99, 1.47)	0.061
10.07-10.59	2.18(1.83, 2.61)	<0.001
≥10.59	3.37(2.84, 4.01)	<0.001
BAI		
<17.00	1.00 (Ref)	-
17.00-19.04	1.20(1.02, 1.41)	0.027
19.04-20.89	1.54(1.33, 1.79)	<0.001
≥20.89	2.12(1.83, 2.44)	<0.001
CI		
<1.11	1.00 (Ref)	-
1.11-1.17	1.11(0.91, 1.34)	0.293
1.17-1.23	2.10(1.78, 2.49)	<0.001
≥1.23	3.36(2.85, 3.95)	<0.001
WHHR		
<0.50	1.00 (Ref)	-
0.50-0.53	1.17(1.00, 1.37)	0.045
0.53-0.56	1.48(1.28, 1.72)	<0.001
≥0.56	1.79(1.55, 2.06)	<0.001

Fig. 2 (See legend on previous page.)

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Table 3 Area under the receiver-operating characteristic curves and cut-off point of the multiple anthropometric indices to predict metabolically obese normal weight (MONW) phenotype, according to sex

Anthropometric indices	AUC (95%CI)	Cut-off value	Sensitivity	Specificity	Youden's index
Male					
Weight	0.538 (0.519, 0.556)	63.850	0.372	0.683	0.055
WC	0.711 (0.693, 0.729)	85.100	0.814	0.498	0.312
HC	0.634 (0.616, 0.653)	94.450	0.622	0.580	0.202
BMI	0.613 (0.596, 0.631)	22.221	0.528	0.652	0.180
WHR	0.613 (0.595, 0.631)	0.882	0.568	0.619	0.187
WHtR	0.733 (0.717, 0.750)	0.486	0.730	0.632	0.362
ABSI	0.651 (0.633, 0.669)	0.066	0.713	0.508	0.221
BRI	0.733 (0.717, 0.750)	3.102	0.730	0.632	0.362
AVI	0.710 (0.692, 0.728)	15.528	0.889	0.422	0.311
WWI	0.706 (0.688, 0.723)	10.339	0.739	0.573	0.312
BAI	0.656 (0.638, 0.674)	18.584	0.640	0.593	0.233
CI	0.698 (0.680, 0.716)	1.245	0.737	0.577	0.314
WHHR	0.626 (0.608, 0.644)	0.510	0.558	0.645	0.203
Female					
Weight	0.587 (0.573, 0.601)	55.750	0.550	0.587	0.137
WC	0.763 (0.751, 0.776)	79.700	0.786	0.665	0.451
HC	0.657 (0.643, 0.671)	89.400	0.522	0.722	0.244
BMI	0.677 (0.664, 0.690)	22.057	0.655	0.612	0.267
WHR	0.643 (0.629, 0.657)	0.841	0.475	0.740	0.215
WHtR	0.773 (0.761, 0.785)	0.488	0.753	0.689	0.442
ABSI	0.652 (0.638, 0.666)	0.066	0.569	0.662	0.231
BRI	0.773 (0.761, 0.786)	3.136	0.753	0.689	0.442
AVI	0.763 (0.750, 0.775)	12.795	0.785	0.665	0.450
WWI	0.732 (0.719, 0.745)	10.249	0.648	0.729	0.377
BAI	0.678 (0.664, 0.692)	19.976	0.674	0.595	0.269
CI	0.729 (0.716, 0.742)	1.194	0.653	0.726	0.379
WHHR	0.656 (0.642, 0.670)	0.526	0.514	0.722	0.236

Abbreviations: *AUC* Area under the receiver-operating characteristic curve, *WC* Waist circumference, *HC* Hip circumference, *BMI* Body mass index, *WHR* Waist-to-hip ratio, *WHtR* Waist-to-height ratio, *ABSI* A body shape index, *BRI* Body roundness index, *AVI* Abdominal volume index, *WWI* Weight-adjusted-waist index, *BAI* Body adiposity index, *CI* Conicity index, *WHHR* Waist-hip-height ratio

diagnostic performances in predicting the MONW phenotype than BMI. Similar findings have been reported in other studies as well [17, 40]. In addition, several studies have indicated that CI [16, 41], BAI [40, 42, 43] ABSI [11, 15, 17, 36–40, 42] and WHHR [40] are inferior obesity indices in predicting metabolic disorders and inflammatory diseases. However, other study found that BAI and WHR had the highest AUCs in identifying diabetes mellitus among men [43]. To date, there have been no studies investigating the recognition capability of CI, BAI, and WHHR for the MONW phenotype. Our study found that CI, BAI, ABSI, and WHHR were less effective in identifying the MONW phenotype compare to BRI, WHtR, AVI, and WWI in both males and females. Therefore, it is crucial to conduct long-term monitoring of these non-invasive anthropometric measures and perform large

prospective follow-up studies to confirm these uncertain results.

Furthermore, our study indicated that the predictive power of novel body fat anthropometric indices, varied depending on gender and age. Specifically, the diagnostic abilities of all anthropometric indices for identifying the MONW phenotype were found to be higher in females compare to males. This observation aligns with similar pattern observed in the relations between central obesity indexes and risk of cardiometabolic risk factors [36], diabetes mellitus [37] and hyperuricemia [38]. We further found the diagnostic capability of anthropometric indicators in detecting the MONW phenotype was higher in pre-menopausal women compared to post- menopausal women. This difference may be partly attributed to males having a greater amount
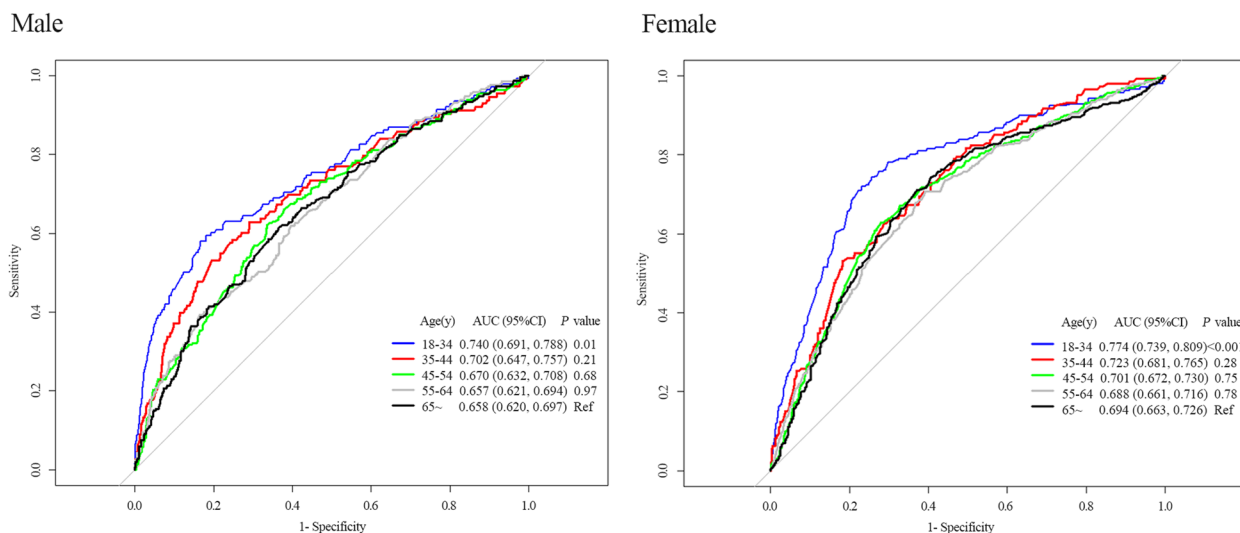
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Fig. 3 ROC curves of the BRI for the identification of the MONW phenotype in subjects of different ages. ROC, receiver operating characteristic; MONW, metabolically obese normal weight; BRI, body roundness index; AUC, area under the receiver-operating characteristic curve

of visceral fat, while females tend to have more subcutaneous adipose tissue [44]. Another possible explanation could be the larger representation of female subjects in our study. Additionally, sex hormones may play a role in body fat distribution and adipocyte differentiation, thereby influencing the association between anthropometric indicators and the MONW phenotype [45]. Moreover, our findings suggested that most novel anthropometric indicators exhibited enhanced predictive power in younger age groups (aged 18–34 years). This observation may be attributed to the development of body size, body composition, chronic metabolic, and coexisting diseases occurring as individuals age [46]. Consequently, it is reasonable to expect that the performance of anthropometric indicators may be influenced by age. However, further investigation is required the underlying mechanism behind these observed differences.

Our findings carry several important implications for clinical practice and public health. Firstly, as non-invasive and simple predictive tools, both BRI and WHtR can assist in reducing the number and cost of invasive tests to some extent, particularly for patients residing in regions with limited medical resources. In addition, BRI could potentially serve as a screening instrument to remind the healthcare professionals of the normal weight individuals at high risk of metabolic abnormalities, providing additional benefits beyond simplex anthropometric indicators traditional. Such early identification of the MONW phenotype enables timely interventions before the onset of adverse consequences, including cardiovascular and metabolic diseases. Based on these considerations, we

recommend the utilization of BRI as a pre-screening tool for identifying the MONW phenotype among the Eastern Chinese population. This approach can help optimize healthcare resource allocation and facilitate targeted interventions for individuals at risk.

Our study has several strengths. Firstly, the main strength of our study is that we systematically and comprehensively compared the associations of the novel indices and traditional indicators with the MONW phenotype concurrently. To the best of our knowledge, no prior research has explored the capabilities of WWI, AVI, BAI, CI, and WHHR for the MONW phenotype in the Chinese population. Secondly, our study boasts a relatively large sample size and encompasses a wide age range of participants, enhancing the robustness and generalizability of findings. Thirdly, multivariable modified poisson regression was applied as it is useful to estimate the covariate-adjusted risk ratios when the outcome is not rare. In addition, sensitivity analyses were conducted to ensure the reliability and stability of our results. Lastly, our study explored various obesity indices in different genders and age, groups. This contributes to the translation of these indices into clinical practice for effectively screening MONW individuals. Nevertheless, there are some limitations that have to be taken consideration. Firstly, the cross-sectional design of the study meant that causality could not be inferred. Secondly, there is no consensus on the definition of MONW, and different definitions may cause unstable results. Thirdly, as a single-center study focused on Chinese adults, there may be limitations in generalizing our findings to other ethnic groups.

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Conclusion

In conclusion, the present study indicated that traditional and novel anthropometric indices were closely associated with the MONW phenotype in both female and male. Among all the anthropometric indices examined, BRI emerged as the most effective tool for identifying the MONW phenotype, particularly among younger individuals. Furthermore, our findings suggested that men with a BRI exceeding 3.102 and women with a BRI surpassing 3.136, irrespective of their general obesity status, are at a high risk of developing the MONW phenotype. These findings could be considered during health policy planning for early detection, early diagnosis and early treatment of MONW individuals. However, further longitudinal studies encompassing a larger and more diverse population are warranted to better explore and confirm the predictive power of these anthropometric indices.

Abbreviations

MHNW	Metabolically health normal weight
MONW	Metabolically obese normal weight
MET	Metabolic equivalent
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
FPG	Fasting plasma glucose
TC	Total cholesterol
TG	Triglycerides
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
BMI	Body mass index
WC	Waist circumference
HC	Hip circumference
WHR	Waist-to-hip ratio
WHtR	Waist-to-height ratio
ABSI	A body shape index
BRI	Body roundness index
AVI	Abdominal volume index
WWI	Weight-adjusted-waist index
BAI	Body adiposity index
CI	Conicity index
WHHR	Waist-hip-height ratio
AUC	Area under the receiver-operating characteristic curve
PR	Prevalence ratio
95%CI	95% confidence interval
SD	Standard deviations
IQR	Interquartile ranges

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-024-19638-9.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Supplementary Material 6

Supplementary Material 7

Supplementary Material 8

Supplementary Material 9

Supplementary Material 10

Supplementary Material 11

Supplementary Material 12

Supplementary Material 13

Supplementary Material 14

Supplementary Material 15

Supplementary Material 16

Declarations

Ethics approval and consent to participate

This study involves human participants and was approved by the Ethics Board of Nanjing Municipal Provincial Center for Disease Control and Prevention (no. PJ2017002). All participants provided written informed consent, and the methods were performed in accordance with relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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