

# BMJ Open Optimised anthropometric indices as predictive screening tools for metabolic syndrome in adults: a cross-sectional study

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## ABSTRACT

**Objectives** We aimed to evaluate the association between metabolic syndrome (MetS) and two latest optimised indices, waist divided by height<sup>0.5</sup> (WHT.5R) and body mass index (BMI) multiply by the square root of BMI and waist circumference (BMI $\sqrt$ WC), and to comprehensively compare the ability of 10 anthropometric indices to identify MetS, including BMI $\sqrt$ WC, WHT.5R, abdominal volume index (AVI), waist-to-height ratio (WHTR), Body Roundness Index (BRI).

**Design** Cross-sectional study.

**Setting** Ningxia, China.

**Participants** A total of 3860 adults aged 18–88 years from Ningxia, China were recruited by a single stratified cluster random sampling method.

**Methods** ORs and 95% CIs for associations between indices and MetS were calculated using binary logistic regression, and areas under the receiver operating characteristic (ROC) curves (AUCs) were performed to compare their predictive capacity for MetS. All results for men and women were analysed and presented separately.

**Results** The highest adjusted ORs for MetS were observed for the following indices: AVI (OR 15.22, 95% CI 10.88 to 21.30), WHT.5R (OR 13.83, 95% CI 9.89 to 19.35) and BMI $\sqrt$ WC (OR 12.14, 95% CI 8.79 to 16.76) in men, whereas BRI, WHTR (both OR 14.91, 95% CI 10.39 to 21.4), WHT.5R (OR 14.22, 95% CI 9.96 to 20.29) and AVI (OR 14.03, 95% CI 9.91 to 19.87) in women. In ROC analysis, AVI (AUC: 0.767 for men and 0.749 for women) and WHT.5R (AUC: 0.761 for men and 0.747 for women) showed the highest predictive ability for MetS.

**Conclusions** BMI $\sqrt$ WC and WHT.5R were significantly positively associated with MetS, and AVI and WHT.5R could be useful screening tools for identifying MetS in both sexes.

## INTRODUCTION

Metabolic syndrome (MetS) is known as a cluster of risk factors for cardiovascular disease and type 2 diabetes mellitus (T2DM),<sup>1</sup> and is associated with kidney disease<sup>2</sup> and many cancers.<sup>3</sup> A review article has reported that obesity is fundamental to MetS as it appears to precede the emergence of the other MetS risk factors.<sup>4</sup> Obesity and MetS have become global major health concern. Despite MRI

## Strengths and limitations of this study

- This is the first study that reports the association between waist divided by height<sup>0.5</sup>, body mass index  $\sqrt$ waist circumference and metabolic syndrome (MetS), and that comprehensively compares the ability of 10 anthropometric indices in identifying MetS.
- The present study performed sensitivity analysis and found that the results did not change significantly.
- This is a cross-sectional design study, with its inherent limited explanation of cause-and-effect temporality.
- The present study defined MetS using International Diabetes Federation 2009 criteria, and therefore, further studies are needed to determine whether the results are consistent under different criteria.

and CT are considered ‘gold standards’ for the measurement of fat distribution, the cost and time of the imaging methods required is prohibitive in many settings.<sup>5</sup> Fortunately, simple, non-invasive and inexpensive anthropometric measurements can evaluate excess adiposity. From a public health perspective, it is therefore important to identify simple and precise anthropometric measurements that reflect adipose tissue distribution and that closely relate to obesity and MetS.

Body mass index (BMI) is the most commonly recommended and used indice to categorise general obesity in clinical and epidemiological studies. However, BMI cannot distinguish muscle mass from fat mass, or reflect fat distribution, and is sometimes affected by age and gender.<sup>6</sup> Alternatively, abdominal obesity indices, such as waist circumference (WC), waist-to-hip ratio (WHR), waist-to-height ratio (WHTR), Body Adiposity Index (BAI), conicity index (C-Index) and abdominal volume index (AVI), have been proposed,<sup>7–10</sup> because they modulate the limitation of BMI. AVI

was proposed as a reliable tool for estimation of overall abdominal volume that was shown to be strongly related to T2DM.<sup>10</sup> Moreover, Body Roundness Index (BRI) and A Body Shape Index (ABSI) were proposed for that they can estimate body fat (BF) distributions.<sup>11 12</sup> BRI was reported to be a predictor of BF and visceral adipose tissue,<sup>11</sup> and was associated with MetS and insulin resistance.<sup>13</sup> ABSI was found to be superior to BMI as predictor of mortality hazard.<sup>12</sup> Recently, two new anthropometric indices have been introduced.<sup>14 15</sup> In 2016, Nevill *et al*<sup>14</sup> developed 'waist divided by height<sup>0.5</sup>', (WHT.5R), and demonstrated that WHT.5R was a waist girth index that was independent of stature, and a stronger predictor of cardiometabolic risk than other anthropometric indices such as WHtR. A recent analytical review provided further support for WHT.5R, which has the strongest association with adiposity while having the weakest correlation with height.<sup>16</sup> In 2019, another new index, BMI multiply by the square root of WC (BMI $\sqrt$ WC), was proposed by using allometric modelling approach in four independent samples, and provided encouraging evidence that BMI $\sqrt$ WC was effective in evaluating percentage BF in children.<sup>15</sup>

There have been many epidemiology investigations on the association between anthropometric indices and MetS, however, the aforementioned study did not examine the association between WHT.5R, BMI $\sqrt$ WC and MetS, and the anthropometric indices compared by previous studies were not identical and comprehensive. Moreover, it is still controversial which the best indice for identifying MetS is. Thus, this study aims, first, to estimate the association between MetS and two latest indices, WHT.5R and BMI $\sqrt$ WC, second, to comprehensively compare the ability of BMI, BMI $\sqrt$ WC, WHR, WHtR, WHT.5R, BRI, BAI, ABSI, C-Index, AVI in identifying MetS from a group of adults in northwest China.

## METHODS

### Study population

This was a cross-sectional study, conducted in July 2010 to November 2011. A total of 4718 subjects were selected using single stratified cluster random sampling in Yinchuan, Wuzhong, Zhongwei, Guyuan and Shizuishan in Ningxia, which is located in northwest China. In the present study, we excluded participants who were under 18 years old or who were pregnant or had cachexia; participants with missing anthropometric, or laboratory measurements were excluded. Visual inspection of the data using boxplots revealed 95 outliers, the population height <1.4m, body weight <35 kg, BMI >50 kg/m<sup>2</sup>, WC >110.5 cm and HDL >3.5 mmol/L. Data were finally analysed from 3860 participants (aged 18–88 years), each with complete anthropometric measurements, biochemical indicator and covariable data (figure 1).

### Patient and public involvement statement

No patient and public involvement was undertaken.

## Anthropometric measurements

Anthropometric measurements were collected by trained staff following standard procedures. Subjects wore light indoor clothing without shoes during body weight and height measurements. WC was measured over the midpoint between the lower border of the ribs and iliac crest in the midaxillary plane. Hip circumference (HC) was measured at the maximum protuberance of the buttocks, which coincides in the front with the symphysis pubis.

## Calculation of anthropometric indices

BMI, BMI $\sqrt$ WC, WHR, WHtR, WHT.5R, BRI, BAI, ABSI, C-Index, AVI were calculated using the following formulas.

- ▶ BMI=weight (kg)/height (m)<sup>2</sup>.
- ▶ BMI $\sqrt$ WC=BMI $\times\sqrt$ WC (m)<sup>15</sup>.
- ▶ WHR=WC(cm)/HC(cm).
- ▶ WHtR=WC (cm)/height (cm).
- ▶ WHT.5R=WC (cm)/height<sup>0.5</sup>(cm)<sup>16</sup>.
- ▶ BRI=364.2–365.5 [1 –  $\pi$  –2 WC<sup>2</sup> (m) Height–2 (m)]<sup>1/2 11</sup>.
- ▶ BAI=HC (m)/Height<sup>1.5</sup> (m)–18<sup>8</sup>.
- ▶ ABSI=WC (m)/[BMI<sup>2/3</sup> (kg/m<sup>2</sup>)Height<sup>1/2</sup> (m)]<sup>12</sup>.
- ▶ C-Index=WC (m)/[0.109 $\times\sqrt$ weight (kg)/height (m)]<sup>9</sup>.
- ▶ AVI=[2 cm (WC)<sup>2</sup>+0.7 cm (WC–HC)<sup>2</sup>/1000]<sup>10</sup>.

## Cardiometabolic risk parameters measurements

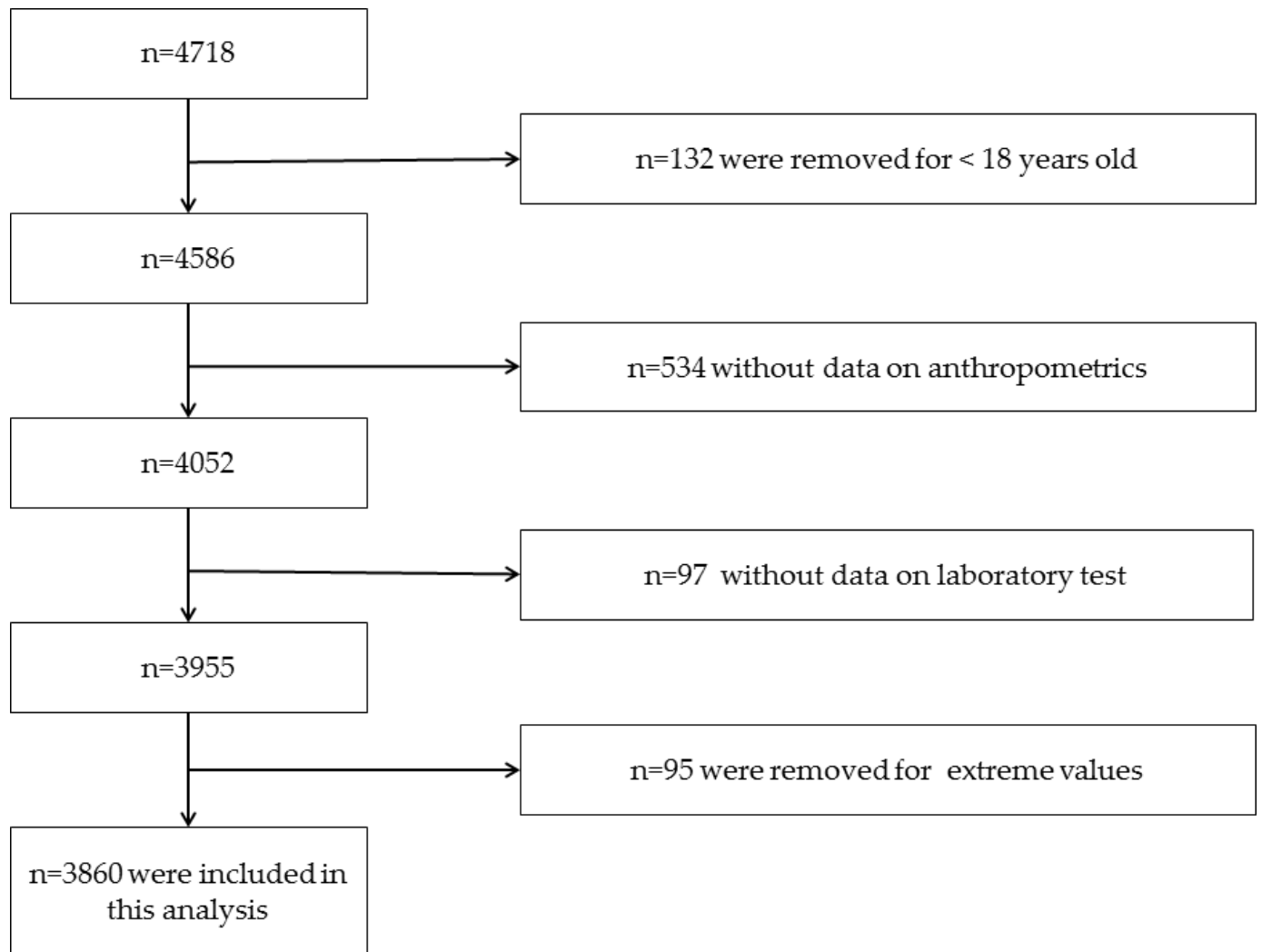
Systolic and diastolic blood pressure (SBP and DBP, mm Hg) were determined in triplicate with use of validated electronic manometer after 5 mins of rest in a sitting position, and the average of three repeated measurements was taken into analysis. Blood samples collected after overnight fast were used to determine serum fasting glucose (FBG, mmol/L), total cholesterol (TC, mmol/L), high-density lipoprotein cholesterol (HDL-C, mmol/L), low-density lipoprotein cholesterol (LDL-C, mmol/L) and triglyceride (TG, mmol/L) levels by standard laboratory enzymatic methods (Hitachi 7060, Tokyo, Japan). Non-HDL cholesterol (Non-HDL-C) was calculated as TC minus HDL-C.<sup>17</sup>

## Diagnostic criteria of MetS

MetS was defined according to the definition of the International Diabetes Federation (IDF) criteria with Chinese-specific abdominal obesity standard.<sup>1</sup> MetS needs at least three of following risk factors: (1) abdominal obesity (WC: men  $\geq$ 85 cm, women  $\geq$ 80 cm); (2) elevated TG (TG  $\geq$ 1.7 mmol/L); (3) low HDL-C (HDL-C: men <1.0 mmol/L), women <1.3 mmol/L); (4) elevated BP (SBP  $\geq$ 130 mm Hg or DBP  $\geq$ 85 mm Hg, or using antihypertension drugs) and (5) elevated (FBG  $\geq$ 5.6 mmol/L or patients previously diagnosed with diabetes).

## Covariables assessment

Data on demographic characteristics, lifestyle habits and personal medical information were collected with



**Figure 1** Flow chart showing the selection of the study sample. The final sample size was 3860 adults, each with complete anthropometric, biochemical indicator and covariable data.

a questionnaire. Education levels were self-reported (no formal, primary, secondary and tertiary), marital status (married, cohabiting, other). A subject was considered a current smoker if he or she smoked regularly in the past month. A subject who consumed alcoholic drinks more than once a week was considered a current drinker. Exercise with moderate-intensity at least 150 min or with vigorous-intensity at least 75 min or an equivalent combination of moderate-intensity and vigorous-intensity activity throughout a week was defined as a regular exerciser.<sup>18</sup> Sedentary time was positively associated with the risk of MetS.<sup>19</sup> Therefore, we also collected the sedentary time of participants. Sedentary time was divided into four levels (Q1<2 hours, 2 hours≤Q2<3 hours, 3 hours≤Q3<5 hours, Q4≥5 hours) according to the quartiles.

Presence of diabetes, hypertension was defined based on clinical history, medications or, respectively, by FBG≥7.0 mmol/L, SBP ≥140 or DBP≥90 mm Hg.<sup>20</sup> Any of the following blood lipid measurements were abnormal: TC ≥6.22 mmol/L or TG ≥2.26 mmol/L or LDL-C ≥4.14 mmol/L or HDL-C ≤1.04 mmol/L or

antihyperlipidemics medication use were considered as criteria for dyslipidaemia.<sup>21</sup>

### Statistical analyses

Subjects were grouped as with MetS and without MetS for men and women, separately. Continuous variables are presented as mean (SD), skewed continuous variables are shown as median (IQR) and categorical variables are described as numbers (percentages). Means, medians and proportions were compared using independent samples t tests, wilcoxon rank-sum tests and  $\chi^2$  tests, respectively. Data normality was verified using Kolmogorov-Smirnov tests and probability plots. Violin plots were used to visualise the distribution of the anthropometric indices and its probability density<sup>22</sup>; point estimates were estimated using means and 95% CIs.

Binary logistic regression was used to evaluate the unadjusted and adjusted associations between anthropometric indices and MetS. The ORs and 95% CIs of quartiles 2–4 (Q2–4) for each index were calculated and compared with quartile 1 (Q1) as a reference group, unless specially



mentioned. The receiver operator characteristic (ROC) curves were used to demonstrate the discriminatory ability of an anthropometric index over the entire range of possible values in the detection of MetS as quantified by the area under the curve (AUC). The optimal cut point for each anthropometric index in detecting MetS was chosen as the point on the curve with the highest Youden Index (sensitivity +specificity-1). The AUCs were compared using a DeLong *et al*<sup>23</sup> non-parametric approach.

Owing to the sexual dimorphism in body composition, the analysis was performed for men and women separately.<sup>24</sup> All models (logistic regression and ROC analysis) were adjusted for the following factors: age, alcohol consumption, sedentary time and physical activity. In addition to these factors, smoking has been added for women in the analysis. These covariables were selected in multi-variable models based on clinical importance or  $p < 0.15$  in univariate analyses. Factors not significantly associated with MetS were excluded from the final model, unless doing so resulted in OR changes of more than 10%.

To test the robustness of our findings, sensitivity analyses using adjusted ROC analyses were performed: (1) owing to the strong correlation between WC and anthropometric indices, we redefined MetS: two out of four components other than WC can be diagnosed as redefined MetS; (2) stratified the age into three groups in men and women separately (age <45, 45 ≤ age <60 and age ≥60); (3) excluded the patients with dyslipidaemia, diabetes, hypertension and obesity (BMI ≥28.0 kg/m<sup>2</sup>).

Statistical analyses were performed using SPSS software, V.22 (IBM) and Stata V.16.0. All statistical tests were two sided, and  $p < 0.05$  was considered statistically significant.

## RESULTS

### Baseline characteristics

The characteristics of the participants, stratified by MetS in men and women, are summarised in [table 1](#). Of the 3860 participants, 1965 were women (50.9%) and 1895 were men (49.1%). MetS according to IDF was found in 41.8% of men, 42.9% of women and 42.4% of all subjects. The prevalence of MetS did not differ significantly between men and women ( $p = 0.508$ ). The men and women with MetS tended to have significantly older age, more sedentary time, less sleep duration and higher body weight, WC, HC, when compared with the participants without MetS ( $p < 0.001$ ). SBP, DBP and FBG, TC, LDL-C, TG, non-HDL-C levels were elevated, whereas HDL-C was decreased in subjects with MetS. Likewise, MetS group had higher prevalence of dyslipidaemia, diabetes, hypertension in men and women. Among MetS components, abdominal obesity, abnormal BP and hyperglycaemic ranked in the top three in both genders. However, no statistically significant differences between the two groups were observed at smoking status and physical activity.

### Obesity indices according to with or without MetS

Online supplemental figures 1 and 2 show the distribution of the anthropometric obesity indices and the mean difference for obesity indices between participants with or without MetS by gender. We found significant differences in all obesity indices in both sexes, and these subjects with MetS tended to have significantly higher anthropometric indices when compared with those participants without MetS ( $p < 0.001$ ).

### Association between MetS and the level of obesity indices

For the analyses of BMI, these participants classified as underweight (BMI <18.5 kg/m<sup>2</sup>) were excluded (n=64 both for males and females), and using normal weight group as a reference group. In unadjusted models, the ORs for MetS increased along with quartiles or stratifications for all ten anthropometric indices in both sexes (online supplemental figure 3). The highest unadjusted ORs for MetS in men were observed for the following indices: AVI (OR 14.65, 95% CI 10.61 to 20.21,  $p < 0.001$ ), WHT.5R (OR 13.42, 95% CI 9.73 to 18.51,  $p < 0.001$ ) and BMI√WC (OR 12.43, 95% CI 9.05 to 17.06,  $p < 0.001$ ). In women, AVI had the highest unadjusted-OR for MetS (OR 16.02, 95% CI 11.54 to 22.23,  $p < 0.001$ ), followed by WHtR, BRI (both OR 15.75, 95% CI 11.35 to 21.84,  $p < 0.001$ ) and WHT.5R (OR 15.62, 95% CI 11.22 to 21.73,  $p < 0.001$ ).

For all analysed anthropometric indices, the ORs for MetS in adjusted models also increased in accordance with the increasing quartiles ([figure 2](#)), whereas they were slightly lower compared with those in the unadjusted models. Moreover, the risk of MetS was not significantly higher only in the second quartiles of ABSI and BAI indicator in females. In men, AVI still had the highest OR for MetS (OR 15.22, 95% CI 10.88 to 21.30,  $p < 0.001$ ), followed by WHT.5R (OR 13.83, 95% CI 9.89 to 19.35,  $p < 0.001$ ) and BMI√WC (OR 12.14, 95% CI 8.79 to 16.76,  $p < 0.001$ ). While, the highest ORs for the occurrence of MetS in women were noted for the following indices: BRI and WHtR (both OR 14.91, 95% CI 10.39 to 21.4,  $p < 0.001$ ), WHT.5R (OR 14.22, 95% CI 9.96 to 20.29,  $p < 0.001$ ) and AVI (OR 14.03, 95% CI 9.91 to 19.87,  $p < 0.001$ ). In contrast, the lowest ORs for MetS were ABSI in both sexes. ABSI and BAI were not shown due to little linkage.

### ROC analysis for the obesity indices for MetS

[Table 2](#) shows the predictive value for each anthropometric index stratified by sex. After controlling for covariates, all adiposity indices still showed acceptable ability to identify MetS. For men, AVI tended to be more useful predictor for MetS (AUC: 0.767, sensitivity 79.6%, specificity 69.7%, cut-off point: 14.45), followed by WHT.5R (AUC: 0.761, sensitivity 77.9%, specificity 68.9%, cut-off point: 6.54). Likewise, for women, AVI had the highest predictive value for MetS (AUC: 0.749, sensitivity 85.4%, specificity 65.2%, cut-off point: 12.80), whereas it did not significantly differ from that of WHT.5R (AUC: 0.747,

**Table 1** Characteristics of the participants with or without MetS in men and women

| Variable                     | Men (n=1895)     |                  |         | Women (n=1965)   |                  |         |
|------------------------------|------------------|------------------|---------|------------------|------------------|---------|
|                              | With MetS        | Without MetS     | P value | With MetS        | Without MetS     | P value |
|                              | 793 (41.8)       | 1102 (58.2)      | –       | 843 (42.9)       | 1122 (57.1)      | 0.508*  |
| Age                          |                  |                  | <0.001  |                  |                  | <0.001  |
| <45                          | 194 (24.5)       | 383 (34.8)       |         | 165 (19.6)       | 448 (39.9)       |         |
| 45–59                        | 240 (30.3)       | 299 (27.1)       |         | 276 (32.7)       | 364 (32.4)       |         |
| ≥60                          | 359 (45.3)       | 420 (38.1)       |         | 402 (47.7)       | 310 (27.6)       |         |
| Education level              |                  |                  | 0.134   |                  |                  | <0.001  |
| No formal/unknown            | 120 (15.1)       | 164 (14.9)       |         | 384 (45.6)       | 347 (30.9)       |         |
| Primary                      | 174 (21.9)       | 227 (20.6)       |         | 123 (14.6)       | 195 (17.4)       |         |
| Secondary                    | 373 (47.0)       | 570 (51.7)       |         | 262 (31.1)       | 470 (41.9)       |         |
| Tertiary                     | 126 (15.9)       | 141 (12.8)       |         | 74 (8.8)         | 110 (9.8)        |         |
| Married/cohabiting           | 725 (91.4)       | 918 (83.3)       | <0.001  | 709 (84.1)       | 966 (86.1)       | 0.218   |
| Smoking status               |                  |                  | 0.699   |                  |                  | 0.216   |
| Non-smoker                   | 580 (73.1)       | 809 (73.4)       |         | 682 (80.9)       | 873 (77.8)       |         |
| Ex-smoker                    | 51 (6.4)         | 61 (5.5)         |         | 6 (0.7)          | 12 (1.1)         |         |
| Current smoker               | 162 (20.4)       | 232 (21.2)       |         | 155 (18.4)       | 237 (21.1)       |         |
| Current drinker              | 154 (19.4)       | 261 (23.7)       | <0.05   | 43 (5.1)         | 111 (9.9)        | <0.01   |
| Regular exerciser            | 364 (45.9)       | 518 (47.0)       | 0.635   | 464 (55.0)       | 615 (54.8)       | 0.920   |
| Sleep duration (h/day)       | 7.07 (1.33)      | 7.18 (1.43)      | 0.087   | 7.04 (1.34)      | 7.17 (1.52)      | <0.05   |
| Sedentary time               |                  |                  | <0.01   |                  |                  | 0.224   |
| Q1 <2 hours                  | 131 (16.5)       | 239 (21.7)       |         | 220 (26.1)       | 282 (25.1)       |         |
| 2hours≤Q<3hours              | 144 (18.2)       | 230 (20.9)       |         | 164 (19.5)       | 261 (23.3)       |         |
| 3hours≤Q3<5 hours            | 267 (33.7)       | 362 (32.8)       |         | 258 (30.6)       | 334 (29.8)       |         |
| Q4 ≥5 hours                  | 251 (31.7)       | 271 (24.6)       |         | 201 (23.8)       | 245 (21.8)       |         |
| Anthropometric               |                  |                  |         |                  |                  |         |
| Height (m)                   | 1.68 (0.07)      | 1.66 (0.07)      | <0.001  | 1.59 (7.18)      | 1.59 (6.19 )     | 0.073   |
| Weight (kg)                  | 73.25 (10.37)    | 65.15 (9.94)     | <0.001  | 65.15 (9.88)     | 58.26 (9.02)     | <0.001  |
| HC (cm)                      | 98.52 (7.03)     | 92.80 (7.26)     | <0.001  | 97.59 (7.29)     | 91.48 (7.41)     | <0.001  |
| WC (cm)                      | 89.56 (8.19)     | 81.18 (8.46)     | <0.001  | 86.50 (8.53)     | 77.57 (8.84)     | <0.001  |
| Cardiometabolic measurements |                  |                  |         |                  |                  |         |
| SBP (mm Hg)                  | 138.53 (15.87)   | 125.86 (17.25)   | <0.001  | 138.42 (18.32)   | 120.65 (17.97)   | <0.001  |
| DBP (mm Hg)                  | 85.26 (10.45)    | 78.81 (10.05)    | <0.001  | 84.47 (10.59)    | 75.89 (9.37)     | <0.001  |
| FBG (mmol/L)                 | 5.90 (5.60–6.45) | 5.30 (4.89–5.67) | <0.001  | 5.81 (5.48–6.30) | 5.12 (4.65–5.48) | <0.001  |
| TC (mmol/L)                  | 4.15 (1.14)      | 4.02 (1.00)      | <0.01   | 4.42 (1.20)      | 4.21 (1.08)      | <0.001  |
| TG (mmol/L)                  | 1.89 (1.25–2.66) | 1.08 (0.78–1.46) | <0.001  | 1.76 (1.14–2.49) | 1.03 (0.73–1.41) | <0.001  |
| LDL-C (mmol/L)               | 2.43 (0.81)      | 2.46 (0.78)      | 0.308   | 2.59 (0.85)      | 2.46 (0.84)      | <0.01   |
| HDL-C (mmol/L)               | 1.11 (0.42)      | 1.37 (0.40)      | <0.001  | 1.31 (0.49)      | 1.51 (0.44)      | <0.001  |
| Non-HDL-C (mmol/L)           | 3.04 (0.95)      | 2.65 (0.87)      | <0.001  | 3.11 (0.93)      | 2.70 (0.91)      | <0.001  |
| MetS components              |                  |                  |         |                  |                  |         |
| Abdominal obesity            | 633 (79.8)       | 336 (30.5)       | <0.001  | 721 (85.5)       | 396 (35.3)       | <0.001  |
| Abnormal BP                  | 665 (83.9)       | 453 (41.1)       | <0.001  | 679 (80.5)       | 315 (28.1)       | <0.001  |
| Hyperglycaemic               | 614 (77.4)       | 306 (27.8)       | <0.001  | 608 (72.1)       | 202 (18.0)       | <0.001  |
| High TG                      | 473 (59.6)       | 170 (15.4)       | <0.001  | 464 (55.0)       | 149 (13.3)       | <0.001  |
| Low HDL-C                    | 380 (47.9)       | 176 (16.0)       | <0.001  | 486 (57.7)       | 335 (29.9)       | <0.001  |
| Chronic diseases             |                  |                  |         |                  |                  |         |

Continued



Table 1 Continued

| Variable      | Men (n=1895) |              |         | Women (n=1965) |              |         |
|---------------|--------------|--------------|---------|----------------|--------------|---------|
|               | With MetS    | Without MetS | P value | With MetS      | Without MetS | P value |
| Dyslipidaemia | 587 (74.0)   | 321 (29.1)   | <0.001  | 484 (57.4)     | 273 (24.3)   | <0.001  |
| Diabetes      | 121 (15.3)   | 45 (4.1)     | <0.001  | 128 (15.2)     | 25 (2.2)     | <0.001  |
| Hypertension  | 447 (56.4)   | 284 (25.8)   | <0.001  | 446 (52.9)     | 210 (18.7)   | <0.001  |

Unknown: men (n=24), women (n=24).

\*Prevalence of men with MetS versus prevalence of women with MetS.

BP, blood pressure; DBP, diastolic blood pressure; FBG, fasting glucose; HC, hip circumference; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; MetS, metabolic syndrome; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

sensitivity 84.7%, specificity 64.4%, cut-off point: 6.31). The values of AUCs, sensitivity and specificity for WHtR, BRI and BMI $\sqrt$ WC were similar, and presented acceptable ability of identifying MetS in males and females. Moreover, BMI and BMI $\sqrt$ WC showed the greatest specificity in men (specificity: 74.1% and 73.6%, respectively) and women (specificity: 66.1% and 67.2%, respectively) for identifying MetS among all the indices we analysed. Conversely, owing to its lower specificity than other indices, the ABSI did not show better prediction, even if its sensitivity was higher than that of several indices (AUC: 0.588, sensitivity 75.5%, specificity 41.7%; AUC: 0.569, sensitivity 74.5%, specificity 48.6%, in men and women, respectively).

### Sensitivity analyses

In sensitivity analysis (online supplemental figures 4 and 5), redefining the MetS, stratifying age or excluding the patients with dyslipidaemia, diabetes, hypertension and obesity did not affect the results significantly. For the redefined MetS, all adiposity indices showed modest ability to identify MetS, except for ABSI in men. Among them, BMI $\sqrt$ WC had the highest adjusted AUC in men and BMI $\sqrt$ WC>AVI= BMI ( $p<0.05$ ), whereas in women, the highest adjusted AUC were for WHT.5R>AVI>BMI $\sqrt$ WC ( $p>0.05$ ). After exclusion of patients with chronic diseases and obesity, AVI had the largest adjusted AUC, followed by WHT.5R and BMI $\sqrt$ WC, but there was no significant difference among them in both genders ( $p>0.05$ ). After age stratification, the largest adjusted AUCs were for AVI and WHT.5R in these groups of age <45 and 45 $\leq$ age<60 in both sexes, while in the group of age  $\geq$ 60, the largest adjusted AUC were for AVI, BMI $\sqrt$ WC and WHT.5R, and the AUCs among them were not statistically significant ( $p>0.05$ ). Interestingly, the AUCs for MetS generally increased along with age stratification in men, while in women generally showed a trend of rising first and then decreasing.

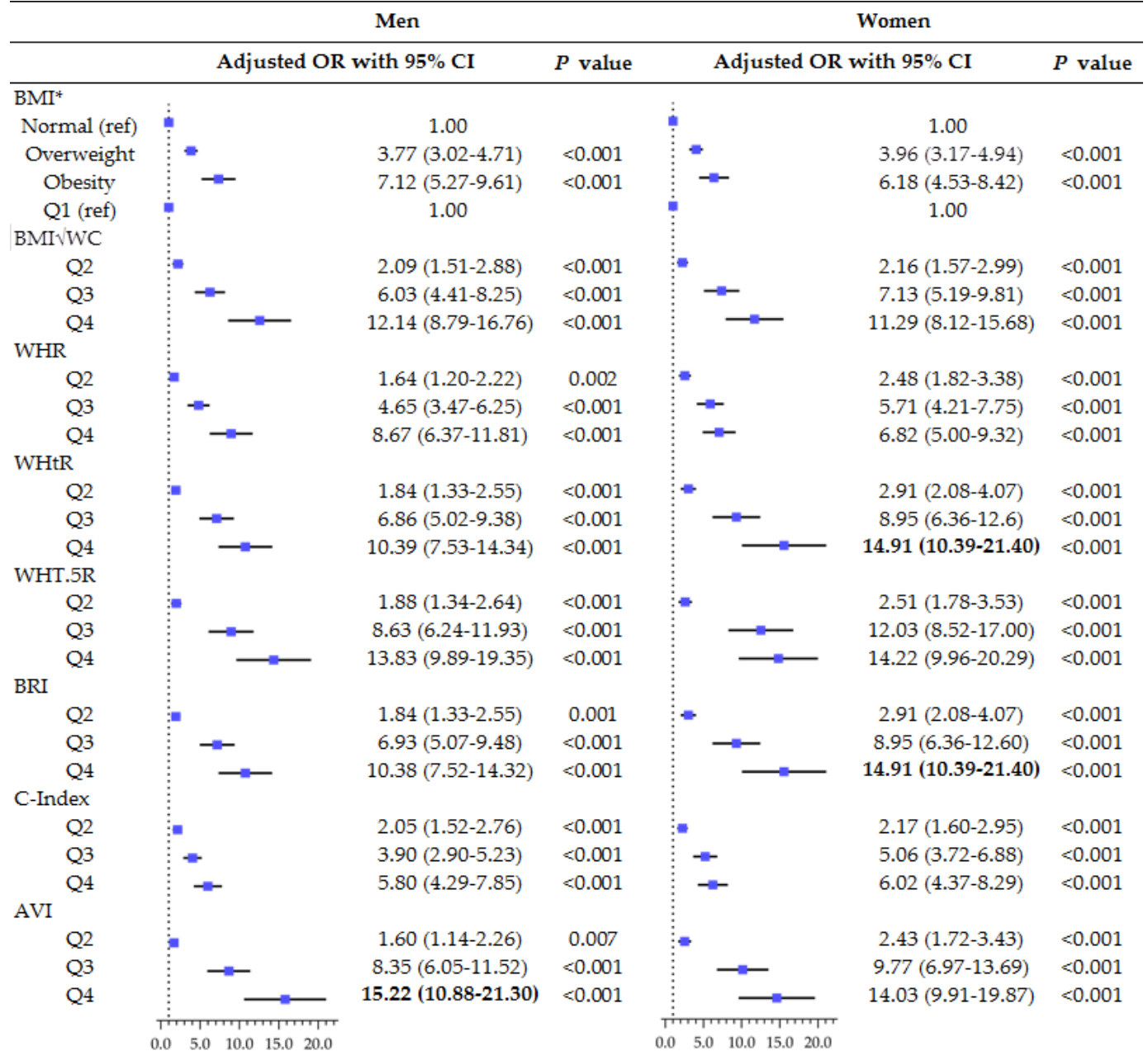
### DISCUSSION

This cross-sectional study comprehensively compared the association of 10 anthropometric indices with MetS in a group of Ningxia adults from northwest China. To the best of our knowledge, no report has previously

investigated the association between WHT.5R, BMI $\sqrt$ WC and MetS. The main findings of this study demonstrated that WHT.5R and BMI $\sqrt$ WC were reliable and easy-to-calculate anthropometric tools for estimation of obesity that were strongly related to MetS. And among the ten indices we analysed, AVI and WHT.5R show superior ability to identify MetS. The results of this study also showed the obesity indices have the different discriminatory ability by gender; therefore, it will be optimal that the sex based measurements are applied to clinical practices and public health.

In the present study, the overall prevalence of MetS was 42.4% according to IDF criteria. The prevalence was higher than Xinjiang (21.8%)<sup>25</sup> and Shaanxi (29.4%),<sup>26</sup> two northwest cities in China, the national level in China (33.9%)<sup>27</sup> and Gujarati Asian Indians (34.3%),<sup>28</sup> whereas, lower than elderly Colombians (58.7%),<sup>29</sup> similar to adults from Colombia (41%).<sup>30</sup> The possible reason may be the difference of the MetS criteria, racial or the age range of the population. The prevalence of MetS also increased with increasing age, which may be led by subtle decreases in basal metabolic rate and physical activity that are not matched with decreases in energy intake.<sup>31</sup>

We demonstrated that WHT.5R is an accurate screening tool for discriminating MetS in both sexes. This result confirms two earlier studies of Nevill *et al*<sup>14 32</sup>, which proposed WHT.5R is a stronger predictor of abdominal adiposity and cardiometabolic risk than other anthropometric indices. Although in line with other authors,<sup>29 33–35</sup> the widely used WHtR also showed better predictive ability for MetS, we would like to emphasise it is not as precise as WHT.5R. A recent analytical review<sup>16</sup> also confirmed the result and explained the reason. They investigated what the optimum value of  $\alpha$  in the index WC/height $^\alpha$  is, proved that WHT.5R ( $\alpha=0.5$ ) showed minimal correlations with height and maximal correlations with BF%, while WHtR ( $\alpha=1$ ) showed the weakest associations with adiposity and the strongest associations with height among the indices they evaluated with scaling powers ranging from 0 to 1.0.<sup>16</sup> Besides the identical variables, WC and Height, as WHT.5R and WHtR,  $\bar{w}$  is added to calculate BRI. It should be noted that WHtR and BRI showed almost the same correlation and predictive



**Figure 2** Adjusted ORs for MetS in quartiles of anthropometric indices in men and women. ORs adjusted for age, alcohol consumption, sedentary time and physical activity (extra added smoking status for women analysis). Normal:  $18.5 \leq \text{BMI} < 24 \text{ kg/m}^2$ ; overweight:  $24 \leq \text{BMI} < 27.9 \text{ kg/m}^2$ ; obesity:  $\text{BMI} \geq 28 \text{ kg/m}^2$ . Those with a  $\text{BMI} < 18.5 \text{ kg/m}^2$  were excluded from these analyses ( $n=64$  for both men and women), and using normal weight group as a reference group. For other anthropometric indices, the first quartile (Q1) was used as a reference group. Q2, second quartile; Q3, third quartile; Q4, fourth quartile. AVI, Abdominal Volume Index; BMI, body mass index;  $\text{BMI}\sqrt{\text{WC}}$ , BMI multiply by sqrt waist circumference; BRI, Body Roundness Index; C-index, conicity index; MetS, metabolic syndrome; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; WHT.5R, waist divided by height<sup>0.5</sup>.

ability with MetS in logistic regression and ROC analysis in both genders. This is consistent with the results that BRI and WHtR have an equal discriminating power for detecting high cardiometabolic risk in older Colombian adults reported by Ramirez-Velez *et al.*<sup>29</sup>. Taken together, a major advantage of WHT.5R over WHtR and BRI appears to be precision and simplicity. Such an advantage could translate to enhanced delivery of public health messages aimed at reducing obesity incidence, as well as the clinical

and public screening of individuals at risk of metabolic abnormality.

$\text{BMI}\sqrt{\text{WC}}$  is a novel obesity index that has just been proposed, for it could effectively predict percentage BF in children.<sup>15</sup> This is the first study to apply  $\text{BMI}\sqrt{\text{WC}}$  to detect MetS in adults, and we found that there was a strong association between  $\text{BMI}\sqrt{\text{WC}}$  and MetS, and it demonstrated an acceptable power for detecting MetS. Our results confirmed the study of Nevill.<sup>15</sup> Owing to the

Table 2 Cut-off points for obesity indices to detect MetS by sex

|                        | BMI                    | BMI/WC                 | WHR                    | WHtR                   | WHR                           | WHtR                   | BRI                    | ABSI                   | BAI                    | C-Index                       | AVI |
|------------------------|------------------------|------------------------|------------------------|------------------------|-------------------------------|------------------------|------------------------|------------------------|------------------------|-------------------------------|-----|
| <b>Men</b>             |                        |                        |                        |                        |                               |                        |                        |                        |                        |                               |     |
| Adjusted-AUC (95% CI)* | 0.723 (0.700 to 0.747) | 0.749 (0.726 to 0.771) | 0.714 (0.690 to 0.739) | 0.745 (0.723 to 0.768) | 0.761 (0.739 to 0.783)        | 0.746 (0.724 to 0.769) | 0.588 (0.561 to 0.614) | 0.654 (0.629 to 0.678) | 0.678 (0.653 to 0.702) | <b>0.767 (0.746-0.789)</b>    |     |
| Optimal cut-off        | 25.14                  | 23.08                  | 0.88                   | 0.51                   | 6.54                          | 3.53                   | 0.08                   | 25.43                  | 1.21                   | 14.45                         |     |
| Youden index           | 0.38                   | 0.43                   | 0.36                   | 0.44                   | 0.47                          | 0.44                   | 0.17                   | 0.26                   | 0.29                   | 0.49                          |     |
| Sensitivity (%)        | 64.3                   | 69.4                   | 69.2                   | 73.8                   | 77.9                          | 73.8                   | 75.5                   | 69.7                   | 66.2                   | 79.6                          |     |
| Specificity (%)        | 74.1                   | 73.6                   | 66.8                   | 70.0                   | 68.9                          | 70.0                   | 41.7                   | 56.6                   | 62.7                   | 69.7                          |     |
| LR(+)                  | 2.48                   | 2.63                   | 2.08                   | 2.46                   | 2.50                          | 2.46                   | 1.30                   | 1.61                   | 1.78                   | 2.63                          |     |
| LR(-)                  | 0.48                   | 0.42                   | 0.46                   | 0.37                   | 0.32                          | 0.37                   | 0.59                   | 0.53                   | 0.54                   | 0.29                          |     |
| <b>Women</b>           |                        |                        |                        |                        |                               |                        |                        |                        |                        |                               |     |
| Adjusted-AUC (95% CI)* | 0.707 (0.683 to 0.732) | 0.732 (0.708 to 0.756) | 0.683 (0.657 to 0.709) | 0.737 (0.713 to 0.761) | <b>0.747 (0.724 to 0.771)</b> | 0.737 (0.713 to 0.761) | 0.598 (0.569 to 0.627) | 0.653 (0.627 to 0.679) | 0.669 (0.642 to 0.696) | <b>0.749 (0.723 to 0.773)</b> |     |
| Optimal cut-off        | 24.04                  | 21.55                  | 0.87                   | 0.50                   | 6.31                          | 3.43                   | 0.08                   | 29.05                  | 1.18                   | 12.80                         |     |
| Youden index           | 0.37                   | 0.43                   | 0.34                   | 0.45                   | 0.49                          | 0.45                   | 0.23                   | 0.34                   | 0.36                   | 0.51                          |     |
| Sensitivity (%)        | 71.1                   | 75.4                   | 70.3                   | 79.1                   | 84.7                          | 79.1                   | 74.5                   | 68.3                   | 78.7                   | 85.4                          |     |
| Specificity (%)        | 66.1                   | 67.2                   | 64.0                   | 66.0                   | 64.4                          | 66.0                   | 48.6                   | 65.3                   | 57.8                   | 65.2                          |     |
| LR (+)                 | 2.10                   | 2.31                   | 1.95                   | 2.33                   | 2.38                          | 2.33                   | 1.45                   | 1.97                   | 1.86                   | 2.46                          |     |
| LR (-)                 | 0.44                   | 0.36                   | 0.46                   | 0.32                   | 0.24                          | 0.32                   | 0.53                   | 0.48                   | 0.37                   | 0.22                          |     |

\*Sex-specific area under the ROC analysis was adjusted for age, alcohol consumption, sedentary time and physical activity, in men. In addition to these factors, smoking status has been added in women analysis. The highest AUC value for MetS is highlighted in bold.

ABSI, A Body Shape Index; AUC, area under curve; AVI, Abdominal Volume Index; BAI, Body Adiposity Index; BMI, body mass index; BMI/WC, BMI multiply by the square root of waist circumference; BRI, Body Roundness Index; C-Index, Conicity Index; LR (+), positive likelihood ratio; LR (-), negative likelihood ratio; ROC, receiver operating characteristic curve; WHtR, waist-to-hip ratio; WHtR, waist-to-height ratio; WHT.5R, waist divided by height 0.5.



introduction of WC as a third dimension, which improves the limitations of using BMI and WC in isolation, BMI $\sqrt$ WC could be a more effective and equally noninvasive proxy for obesity and MetS, and the assessment of BMI $\sqrt$ WC is no more time-consuming or arduous than BMI and WC separately. Moreover, it is worth noting that BMI $\sqrt$ WC showed the greatest specificity (67.2%) in women and the second greatest specificity (73.6%) in men for discriminating MetS among all the indices we analysed. Based on above discussion, it may also have some value in clinical settings and public health.

Our findings also provided strong evidence that AVI is a reliable anthropometric tool for identifying MetS in both sexes.<sup>36–38</sup> Interestingly, in consistent with Guerrero-Romero and Rodríguez-Morán<sup>10</sup> despite the fact that the same variables, WC and HC, were used to calculate the WHR and AVI, a high agreement was not obtained between the two indices from our findings. Because AVI was an estimation of overall abdominal volume that theoretically included both intra-abdominal fat and adipose tissue volume, and possessed the advantage of considering the gender-dependent fat distribution,<sup>10</sup> it can explain the high association between AVI and MetS, as well as its superiority to WHR and other indices.

Although C-Index, BAI and ABSI showed positive associations with MetS, they are not effective screening tools for MetS in both sexes. These observations are consistent with previous studies,<sup>39–42</sup> and a prospective, longitudinal study in Chinese adults.<sup>43</sup> Lawrence *et al*<sup>37</sup> reported that C-Index showed better performance in the prediction of MetS and its components only in apparently healthy Ghanaian females. Thus, combined with our findings and that of previous studies, it can be concluded that C-Index, BAI and ABSI do not seem to be useful obesity indices for detecting MetS. Otherwise, we would like to emphasise although BRI, AVI showed a better ability to identify MetS, they are of difficult use due to the complicated formulas.

There are limitations with this study. First, this is a cross-sectional design study, with its inherent limited explanation of cause-and-effect temporality. Therefore, further cohort studies using a prospective design are needed to evaluate the relation between anthropometric measurements and MetS and the validity of the obtained cut-off values. Second, although we statistically adjusted for confounding factors, the adjustment may not have entirely removed confounding factors. Third, the effects of dyslipidaemia, hypertension, diabetes and other medications, which may be affecting the value of blood biochemical measurements, were not considered. Fourth, these participants of this study were only from a region in northwest China. Hence, these results may be not completely applicable to other populations. Finally, the present study defined MetS using IDF 2009 criteria. Therefore, further studies are needed to determine whether the results are consistent under different criteria. Despite these limitations, strengths of this paper include: (1) the large sample size, and the participants covers in

each region of Ningxia, which allowed us to obtain solid results that are comparable to those of other studies; (2) the use of standardised methodological procedures in our study, which minimised measurement bias; (3) sensitivity analyses were performed and the results did not change significantly and (4) we provided gender-specific thresholds for various surrogate anthropometric indices.

## CONCLUSIONS

In conclusion, results from this cross-sectional analysis indicated that WHT.5R and BMI $\sqrt$ WC had significantly positive association with MetS in both sexes and AVI, WHT.5R could be useful screening tools for identifying MetS in both sexes. However, some of these indices are not easy to calculate, thus if being aided with practical software, may be potentially applied to identify at-risk individuals for further clinical evaluations. Considering the BMI and BMI $\sqrt$ WC tended to higher specificity, while abdominal obesity index tended to higher sensitivity for identifying MetS, the use of both generalised and abdominal index in clinical and public health would improve the accuracy of screening obesity and health risk phenotyping beyond each index alone, which deserves further study.

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