Original Article

Predicting Metabolic Syndrome Using Anthropometric Indices among Chinese Adolescents with Different Nutritional Status: A Multicenter Cross-sectional Study*

LI Ya Mei[1,&], ZOU Zhi Yong[2,&], MA Ying Hua[2], LUO Jia You[1], JING Jin[3], ZHANG Xin[4], LUO Chun Yan[5], WANG Hong[6], ZHAO Hai Ping[7], PAN De Hong[8], and LUO Mi Yang[1,#]

1. Xiangya School of Public Health, Central South University, Changsha 410008, Hunan, China; 2. Institute of Child and Adolescent Health, Peking University School of Public Health, National Health Commission Key Laboratory of Reproductive Health, Beijing 100191, China; 3. Department of Maternal and Child Health, School of Public Health, Sun Yat-sen University, Guangzhou 510080, Guangdong, China; 4. School of Public Health, Tianjin Medical University, Tianjin 300070, China; 5. Department of School Health, Shanghai Municipal Center for Disease Control and Prevention & Shanghai Institutes of Preventive Medicine, Shanghai 200336, China; 6. School of Public Health and Management, Chongqing Medical University, Chongqing 400016, China; 7. School of Public Health and Management, Ningxia Medical University, Yinchuan 750004, Ningxia, China; 8. Liaoning Health Supervision Bureau, Shenyang 110000, Liaoning, China

Abstract

Objective To evaluate the predictive performance of anthropometric indices for metabolic syndrome (MetS) among Chinese adolescents with different nutritional status.

Methods We recruited 9,513 adolescents aged 10–18 years from seven provinces in China during September 2014. Anthropometric indices and blood pressure were measured at recruitment, and blood samples were collected for determining fasting plasma glucose and lipid profile. Receiver operating characteristic (ROC) analyses were used to assess the predictive performance of anthropometric indices, including body mass index (BMI) percentile, waist circumference percentile, waist-height ratio, and waist-hip ratio.

Results Overall, the four anthropometric indices showed good accuracy for predicting MetS with areas under ROC curves (AUCs) ranging from 0.86 to 0.94; similar AUCs ranging from 0.73 to 0.99 were observed for participants with normal weight. The performance of all four indices was poor in overweight and obese participants, with AUCs ranging from 0.66 to 0.77 and from 0.60 to 0.67, respectively. Waist circumference showed relatively better performance in all the subgroup analyses.

Conclusions We suggest using anthropometric indices with the cutoff values presented here for predicting MetS in the overall and normal-weight adolescent population, but not in the overweight and obese adolescent population where more specific screening tests are required.

Key words: Metabolic syndrome; Anthropometry; Body mass index; Waist circumference; Waist-height ratio; Waist-hip ratio; Adolescents

Biomed Environ Sci, 2021; 34(9): 673-682 *doi: 10.3967/bes2021.095* *ISSN: 0895-3988*

www.besjournal.com (full text) *CN: 11-2816/Q*

*This study was supported by the Medical Research Council, the Research Special Fund for Public Welfare of Health [Grant No. 201202010] and Hunan Provincial Natural Science Foundation of China [Grant No. 2018JJ2553].

&These authors contributed equally to this work.

#Correspondence should be addressed to LUO Mi Yang, E-mail: miyangluo@csu.edu.cn

Biographical notes of the first authors: LI Ya Mei, female, born in 1989, PhD, majoring in childhood obesity and metabolic diseases; ZOU Zhi Yong, male, born in 1985, PhD, majoring in early life nutrition on adolescent health.

INTRODUCTION

Metabolic syndrome (MetS) is a cluster of cardiovascular and diabetic risk factors, including abdominal obesity, hypertriglyceridemia, decreased high-density lipoprotein cholesterol (HDL), hyperglycemia, and hypertension[1,2]. One-quarter of adults were estimated to have MetS worldwide in 2015[3]. Driven by the growing obesity epidemic, the prevalence of MetS in children has increased over the recent decades[4,5]. MetS in childhood is likely to develop into lifelong health threats, predisposing the individuals to MetS, type 2 diabetes, and cardiovascular diseases (CVD) in adulthood[6,7]. Early screening of MetS in youths is considered to be an effective primary care strategy for preventing cardiovascular and metabolic diseases[6,7].

Although the components of MetS are mostly determined by objective approaches (e.g., laboratory tests), noninvasive and easy adiposity-related anthropometric measurements such as body mass index (BMI) and waist circumference have been proposed as feasible alternatives for identifying MetS in early stages because of the robust relationship between childhood obesity and MetS[4,8]. Many studies have reported good predictive capabilities of anthropometric indices for MetS among children and adolescents, with the area under receiver operating characteristic (ROC) curve (AUC) greater than 0.7[9-13]. For instance, one study on 16,914 participants aged 7–17 years reported that BMI z-score, waist circumference z-score, and waist-height ratio showed a good prediction for MetS with AUCs around 0.90, and waist-height ratio showed the best performance[10]. There is, however, little evidence on the applicability of anthropometric indices to predict MetS among adolescents with different nutritional status. It is widely observed that the prevalence of MetS is high in overweight and obese population[14]. Some studies have also shown that overweight and obesity without MetS do not increase the risk for CVD, but the presence of MetS significantly increased the risk for CVD and mortality[15,16]; this suggests the importance of identifying MetS in overweight and obese population for early intervention.

By conducting a cross-sectional study in primary and secondary students from seven provinces in China, we aimed to investigate the accuracy of four commonly used adiposity-related anthropometric indices, namely BMI percentile, waist circumference percentile, waist-height ratio, and waist-hip ratio, in identifying MetS among Chinese adolescents with different nutritional status. Our research covers the vast majority of Chinese adolescents, as 92.3% of the enrolled children had completed nine-year compulsory education in China and the enrollment rate of senior high school students was 86.0%[17]. The findings of the present study will contribute to better understanding of the effectiveness of these indices in MetS risk screening.

METHODS

Study Design and Participants

This study used the baseline data of a multicenter intervention study conducted in September 2013. Details of the intervention study have been described in previous publications[18,19]. Briefly, a multistage stratified cluster sampling method was used to recruit adolescents from seven provinces or municipality of China, including Liaoning, Tianjin, Shanghai, Hunan, Guangdong, Ningxia, and Chongqing, which covered all the seven geographical areas of China. In each province or municipality, 12–16 primary and secondary schools were randomly selected, and two classes were randomly selected from each grade for participant recruitment. A total of 16,756 students were recruited in the study. Participants with missing data for anthropometric measurements (n = 694), blood pressure (n = 92), fasting plasma glucose (n = 10), or lipid levels (n = 262) and those aged under 10 years (n = 6,185) were excluded from this study. The final analysis included a total of 9,513 adolescents aged 10–18 years.

This study was approved by the Ethical Committee of the Peking University Health Science Center (Approval No. IRB00001052-13034). Written informed consent was obtained from all the participating students and their parents.

Study Measurements

At recruitment, height, weight, and waist and hip circumferences were measured by experienced technicians following standard procedures. Standing height was measured to the nearest 0.1 cm using a fixed stadiometer (model RGT-140, China), and body weight was measured using a lever-type weight scale to the nearest 0.1 kg (model TZG, China). Waist and hip circumferences were also measured to the nearest 0.1 cm.

Blood pressure was measured according to the recommendation of the National High Blood

Pressure Education Program Working Group in Children and Adolescents[20] by using mercury sphygmomanometers (model XJ11D, China) and stethoscopes (model TZ-1, China). The participants were asked to sit quietly for at least 5 min before the first reading. Systolic blood pressure was determined by the onset of the first Korotkoff sound, and diastolic blood pressure was determined by the fifth Korotkoff sound. Blood pressure was measured twice with a 5-min gap between two measurements, and mean systolic and diastolic blood pressures were calculated.

After an overnight fast of 12 h, venous blood samples (2 mL) were obtained between AM 7:00–9:00 from the antecubital vein of each participant and collected into EDTA vacuum tubes. The samples were centrifuged at 1,509 x*g*, aliquoted, and stored at −80 °C. Levels of fasting plasma glucose, high density lipoprotein (HDL), and triglyceride (TG) were measured at a validated biomedical analysis laboratory. The glucose level was measured using the glucose oxidase method; the HDL level was measured using the clearance method; and the TG level was measured using the enzymatic method.

Adiposity-related Anthropometric Indices

Age- and sex-specific BMI percentiles were calculated based on the BMI growth charts for Chinese children and adolescents[21]. Four types of nutritional status, namely lean, normal weight, overweight, and obesity, were defined based on the age- and sex-specific BMI cutoffs equivalent to < 18 kg/m^2, 18–23.9 kg/m^2, ≥ 24 kg/m^2, and ≥ 28 kg/m^2 at 18 years of age, respectively[21]. Age- and sex-specific waist circumference percentiles were calculated based on the waist circumference growth charts for Chinese children and adolescents[22]. The waist-height ratio was calculated by dividing waist circumference by height. The waist-hip ratio was calculated by dividing waist circumference by hip circumference.

Definition of MetS

According to the criteria proposed by the International Diabetes Federation[2], MetS is defined by the presence of central obesity (< 16 years old: waist circumference ≥ age- and sex-specific 90th percentile; ≥ 16 years old: waist circumference ≥ 90 cm in males and ≥ 80 cm in females) and at least two other compromised components, including high TG (TG ≥ 1.7 mmol/L), low HDL (< 16 years: HDL < 1.03 mmol/L, ≥ 16 years: HDL < 1.03 mmol/L in males and < 1.29 mmol/L in females), hyperglycemia (fasting plasma glucose ≥ 5.6 mmol/L), and elevated blood pressure (systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg).

Statistical Analyses

Participant characteristics were compared among different nutritional status. Continuous variables were expressed as median and interquartile range, and categorical variables were expressed as frequency and percentage. The normality of continuous data was examined by Lilliefors and Shapiro-Wilk tests, which revealed that continuous variables were not normally distributed. The Kruskal-Wallis test and the chi-square test were used for comparing anthropometric indices and MetS components between different nutritional status. Partial correlations were performed between MetS components and anthropometric indices after adjusting for age and gender. ROC analyses were used to assess the predictive accuracy of anthropometric indices for MetS and its components. The AUC provides a measure of the model's discriminatory ability. AUC should be greater than 0.5; the closer the AUC is to 1, the better is the diagnostic effect[23]. Pairwise comparisons of AUCs in models predicted using BMI percentile, waist circumference percentile, waist-height ratio, and waist-hip ratio within each group were conducted using the DeLong test[24]. *Z* test was used for comparing the AUCs predicted using the same variable in the overweight or obese group compared to the normal group. Multivariable logistic regression analysis was conducted for the total population and separately for children with different nutritional status to identify the strength of association of different indices (adjusting for age, sex, ethnicity, region, and home location) and MetS. ROC analyses and comparisons were conducted in MedCalc (MedCalc Software Bvba, Ostend, Belgium), and other statistical analyses were performed using SPSS for Windows (version 21.0, SPSS Inc., Chicago, IL, USA).

RESULTS

Basic Characteristics of the Studied Sample

As shown in Table 1, a total of 9,513 children and adolescents aged 10–18 years were included in the analysis, and 51.5% of the sample were boys. The lean, overweight, and obese rates were 6.9%, 15.8%, and 10.0% respectively, with a larger proportion of boys than girls in the lean and obese groups. Han nationality accounted for the overwhelming majority, and no significant differences in nutritional status were observed between the Han group and the minority ethnicity groups. Each study region consisted of 13.6% to 15.9% of study subjects, and 58.0% of subjects lived in urban areas.

Table 2 shows anthropometric indices and MetS components stratified by nutritional status. From the lean group to the obese group, all the anthropometric indices and MetS variables presented an increasing trend, except for HDL that showed a decreasing trend. The prevalence of MetS components including central obesity, low HDL, high TG, hyperglycemia, and elevated blood pressure also increased from the lean group to the obese group. Overall, 2.84% of subjects from the total sample were detected to have MetS. The prevalence of MetS was 0.14% in the normal group, 4.47% in the overweight group, 20.38% in the obese group, and 0% in the lean group.

Predictive Performance of Anthropometric Indices for MetS Stratified by Nutritional Status

Table 3 shows the predictive performance of anthropometric indices for MetS. The four anthropometric indices showed good accuracy for predicting MetS, with AUCs ranging from 0.86 to 0.94 for the total sample. Waist circumference percentile showed the best AUC, followed by BMI percentile and waist-height ratio, while waist-hip ratio showed the lowest AUC. The cutoff value was determined based on the plot of ROC (Supplementary Figure S1, available in www. besjournal.com). Waist circumference percentile yielded the optimal accuracy at the cutoff of the 90th percentile. In addition, the odds ratio of MetS was the highest for one decile increase in the WC percentile as compared to all the other indices in the logistic regression models, after adjustment for age, sex, ethnicity, region, and home location (Supplementary Figure S2, available in www. besjournal.com).

Further analyses were conducted for different nutritional status. In the normal group, waist circumference percentile, waist-height ratio, and waist-hip ratio showed a good range of AUCs from 0.89 to 0.99, but BMI percentile showed fair discrimination (AUC = 0.73) for MetS. In the overweight group, waist circumference percentile

Table 1. Sociodemographic characteristics of the studied adolescents

Item	Lean group	Normal group	Overweight group	Obese group	Overall	*P*
N (%)	652 (6.85)	6,409 (67.37)	1,500 (15.77)	952 (10.01)	9,513 (100.00)	
Age (years, mean ± SD)	13.44 ± 2.34	13.39 ± 2.19	13.07 ± 2.22	12.74 ± 2.30	13.28 ± 2.23	< 0.001
Sex (*n*, %)						< 0.001
Boys	425 (8.68)	3,078 (62.88)	780 (15.93)	612 (12.50)	4,895 (51.46)	
Girls	227 (4.92)	3,331 (72.13)	720 (15.59)	340 (7.36)	4,618 (48.54)	
Ethnicity (*n*, %)						0.078
Han	599 (6.73)	5,982 (67.24)	1,416 (15.92)	900 (10.12)	8,897 (93.52)	
Minorities	53 (8.60)	427 (69.32)	84 (13.64)	52 (8.44)	616 (6.48)	
Region (*n*, %)						< 0.001
Hunan	71 (5.41)	1,039 (79.19)	149 (11.36)	53 (4.04)	1,312 (13.79)	
Ningxia	96 (7.15)	986 (73.47)	186 (13.86)	74 (5.51)	1,342 (14.11)	
Tianjin	87 (5.74)	885 (58.38)	294 (19.39)	250 (16.49)	1,516 (15.94)	
Chongqing	89 (6.90)	903 (70.05)	195 (15.13)	102 (7.91)	1,289 (13.55)	
Liaoning	85 (6.05)	866 (61.68)	252 (17.95)	201 (14.32)	1,404 (14.76)	
Shanghai	66 (5.07)	836 (64.26)	241 (18.52)	158 (12.14)	1,301 (13.68)	
Guangzhou	158 (11.71)	894 (66.27)	183 (13.57)	114 (8.45)	1,349 (14.18)	
Home location (*n*, %)						0.014
Urban	403 (7.30)	3,753 (67.99)	840 (15.22)	524 (9.49)	5,520 (58.03)	
Rural	249 (6.24)	2,656 (66.52)	660 (16.53)	428 (10.72)	3,993 (41.97)	

exhibited fair discrimination (AUC = 0.77) for MetS, while other indices showed poor AUCs ranging from 0.66 to 0.69. In the obese group, poor discriminatory abilities were observed for all the anthropometric indices for MetS, with AUCs ranging from 0.60 to 0.67. The Youden indices suggested that waist circumference percentile had a better performance than the other three measures in all subgroup analyses. We also performed the age- and sex-adjusted AUCs for the abovementioned analyses, which showed similar results (Supplementary Table S1, available in www.besjournal.com).

AUCs of Anthropometric Indices for MetS Components Stratified by Nutritional Status

Table 4 shows the AUCs of anthropometric indices for each MetS component. In the total sample, the four anthropometric indices exhibited a better prediction for central obesity, with AUCs ranging from 0.87 to 0.99, while the prediction for low HDL and hypertension had AUCs below 0.6 for most cases. BMI percentile, waist circumference percentile, and waist-height ratio showed a better performance in general than waist-hip ratio.

Similar results were observed in the stratified analysis. All anthropometric indices showed a relatively good prediction for central obesity, with AUCs ranging from 0.74 to 0.99; waist circumference percentile showed the best AUCs. Poor prediction ability was observed for low HDL, high TG, hyperglycemia, and elevated blood pressure, with AUCs below 0.6.

DISCUSSION

The increasing incidence of MetS in adolescents has been a growing public concern worldwide. In the present study, the overall prevalence of MetS

Table 2. Distribution of anthropometric indices and MetS components in the studied adolescents in different nutritional status

Item	Lean group (median, IQR, or *n*, %)	Normal group (median, IQR, or *n*, %)	Overweight group (median, IQR, or *n*, %)	Obese group (median, IQR, or *n*, %)	Overall (median, IQR, or *n*, %)	*P*
Anthropometric indices						
BMI percentile	6.37 (3.22–9.18)	49.60 (31.56–68.08)	91.77 (88.49–94.74)	99.08 (98.09–99.64)	60.26 (33.00–85.54)	< 0.001
WC percentile	20.33 (9.38–33.00)	59.87 (40.52–75.80)	91.31 (84.67–94.95)	97.78 (95.99–98.90)	68.44 (43.25–88.10)	< 0.001
Waist-height ratio	0.38 (0.37–0.40)	0.42 (0.40–0.44)	0.48 (0.46–0.50)	0.55 (0.52–0.57)	0.43 (0.40–0.47)	< 0.001
Waist-hip ratio	0.80 (0.77–0.83)	0.81 (0.78–0.84)	0.86 (0.82–0.89)	0.91 (0.86–0.95)	0.82 (0.78–0.86)	< 0.001
MetS components						
HDL (mmol/L)	1.39 (1.21–1.60)	1.33 (1.14–1.55)	1.24 (1.07–1.45)	1.14 (0.98–1.32)	1.30 (1.11–1.51)	< 0.001
TG (mmol/L)	0.81 (0.63–1.05)	0.85 (0.66–1.10)	0.95 (0.75–1.24)	1.15 (0.85–1.60)	0.88 (0.68–1.16)	< 0.001
Glucose (mmol/L)	4.67 (4.32–5.05)	4.70 (4.35–5.02)	4.83 (4.51–5.13)	4.90 (4.54–5.26)	4.74 (4.39–5.06)	< 0.001
SBP (mmHg)	101.00 (95.25–110.00)	106.00 (99.00–113.00)	110.00 (102.00–120.00)	118.00 (110.00–121.00)	108.00 (100.00–117.00)	< 0.001
DBP (mmHg)	65.00 (60.00–71.00)	68.00 (60.00–72.00)	70.00 (61.00–76.00)	71.00 (68.00–80.00)	69.00 (60.00–73.00)	< 0.001
Central obesity	5 (0.77)	229 (3.57)	747 (49.80)	903 (94.85)	1,884 (19.80)	< 0.001
Low HDL	88 (13.50)	1,090 (17.01)	354 (23.60)	318 (33.40)	1,850 (19.45)	< 0.001
High TG	20 (3.07)	281 (4.38)	142 (9.47)	208 (21.85)	651 (6.84)	< 0.001
Hyperglycemia	19 (2.91)	194 (3.03)	65 (4.33)	75 (7.88)	353 (3.71)	< 0.001
Elevated BP	7 (1.07)	178 (2.78)	114 (7.60)	162 (17.02)	461 (4.85)	< 0.001
MetS	0 (0.00)	9 (0.14)	67 (4.47)	194 (20.38)	270 (2.84)	< 0.001

Note. BMI: body mass index; BP: blood pressure; DBP: diastolic blood pressure; HDL: high density lipoprotein; IQR: interquartile range; MetS: metabolic syndrome; SBP: systolic blood pressure; TG: triglyceride; WC: waist circumference.

was 2.8%, which is consistent with a previous study in China (3.3%)[25]. All anthropometric indices, including BMI percentile, waist circumference percentile, waist-height ratio, and waist-hip ratio, showed good predictive performance with AUCs greater than 0.8 in the total sample. When stratified by nutritional status, the predictive performance of all the indices significantly decreased in the overweight and obese groups compared to that in the normal group. Comparatively, waist circumference percentile showed better performance for predicting MetS than the other three measures.

Although MetS and its components were more prevalent in the overweight and obese groups, the AUCs of most anthropometric indices among the overweight and obese groups were less than 0.7. Consistently, many studies have shown that BMI, waist circumference, waist-height ratio, waist-hip ratio, and other indicators had limited predictive accuracy for MetS in obese adolescents[11,13,26]. The majority of overweight/obese subjects had high levels of waist circumference and waist-height ratio[27]; thus, the discriminatory accuracy in these subjects was limited by smaller intervals of anthropometric indices. In contrast, among subjects with normal BMI, all anthropometric indices showed a good predictive performance for MetS in terms of

Table 3. Areas under the receiver operating characteristic curves, optimal cutoff points, and validity parameters of different anthropometric indices in predicting MetS by nutritional status[1]

Indices	AUC (95% *CI*)	Cutoff value	Sensitivity (%)	Specificity (%)	Youden index
Total sample					
BMI percentile	0.93 (0.92–0.94)[2,4]	89.97th	93.70	82.43	0.76
WC percentile	0.94 (0.94–0.95)[5,6]	89.97th	100.00	79.91	0.80
Waist-height ratio	0.93 (0.92–0.94)[7]	0.47	94.81	79.57	0.74
Waist-hip ratio	0.86 (0.84–0.88)	0.85	83.33	72.81	0.56
Normal group					
BMI percentile	0.73 (0.53–0.93)[2,3]	52.79th	88.89	54.48	0.43
WC percentile	0.99 (0.98–1.00)[5,6]	90.15th	100.00	94.91	0.95
Waist-height ratio	0.98 (0.96–0.99)[7]	0.46	100.00	90.78	0.91
Waist-hip ratio	0.89 (0.85–0.94)	0.84	100.00	77.11	0.77
Overweight group					
BMI percentile	0.69 (0.63–0.75)[2]	92.65th	71.64	59.32	0.31
WC percentile	0.77 (0.73–0.81)[5,6,8]	89.97th	100.00	45.08	0.45
Waist-height ratio	0.68 (0.62–0.74)[8]	0.47	83.58	41.87	0.25
Waist-hip ratio	0.66 (0.60–0.73)[8]	0.87	58.21	64.27	0.22
Obese group					
BMI percentile	0.63 (0.58–0.67)[2]	99.06th	69.07	54.88	0.24
WC percentile	0.67 (0.63–0.71)[6,9]	97.50th	75.26	51.45	0.27
Waist-height ratio	0.64 (0.60–0.68)[7,9]	0.53	76.29	43.67	0.20
Waist-hip ratio	0.60 (0.56–0.65)[9]	0.92	53.61	63.72	0.17

Note. [1]Abbreviations: AUC: area under receiver operating characteristic curve; BMI: body mass index; *CI*: confidence interval; MetS: metabolic syndrome; WC: waist circumference. [2]Significant difference in the AUCs of BMI percentile and WC percentile ($P < 0.05$). [3]Significant difference in the AUCs of BMI percentile and waist-height ratio ($P < 0.05$). [4]Significant difference in the AUCs of BMI percentile and waist-hip ratio ($P < 0.05$). [5]Significant difference in the AUCs of WC percentile and waist-height ratio ($P < 0.05$). [6]Significant difference in the AUCs of WC percentile and waist-hip ratio ($P < 0.05$). [7]Significant difference in the AUCs of waist-height ratio and waist-hip ratio ($P < 0.05$). [8]Significant difference in AUCs between the normal and overweight groups ($P < 0.05$). [9]Significant difference in AUCs between the normal and obese groups ($P < 0.05$).

AUCs, sensitivity, specificity, positive predictive value, and negative predictive value. Our findings suggest that anthropometric indices, especially waist circumference-related indices, can be used as an effective and convenient tool for screening MetS in the overall population and subjects with normal BMI. For overweight and obese adolescents, more specific diagnostic tests should be conducted, considering the poor predictive power of anthropometric indices and relatively low costs of diagnostic tests for MetS components.

In our present study, the four anthropometric indices showed good ranges of AUCs for MetS and central obesity; however, poor to fair accuracy was observed for the other MetS components, with AUCs ranging from 0.53 to 0.73 in the overall population. The findings were consistent with existing studies that anthropometric indices predicted MetS well but had comparatively poorer accuracy for dyslipidemia, hypertension, and hyperglycemia in children and adolescents[28,29]. In a recent meta-analysis, the pooled AUCs for predicting MetS, elevated TG, low HDL, hypertension, and hyperglycemia by using BMI, waist circumference, and waist-height ratio were 0.81–0.87, 0.67–0.73, 0.69–0.70, 0.64–0.68, and

Table 4. AUCs and 95% confidence intervals of the four anthropometric indices for each MetS component by nutritional status[1]

Indices	Central obesity	Low HDL	High TG	Hyperglycemia	Elevated BP
Total sample					
BMI percentile	0.96 (0.95–0.96)[2,3,4]	0.59 (0.58–0.61)[2,4]	0.71 (0.68–0.73)[4]	0.59 (0.55–0.62)	0.73 (0.70–0.75)[3,4]
WC percentile	0.99 (0.99–0.99)[5,6]	0.61 (0.59–0.62)[5,6]	0.70 (0.68–0.72)[6]	0.58 (0.55–0.61)	0.72 (0.69–0.74)[5,6]
Waist-height ratio	0.97 (0.97–0.98)[7]	0.59 (0.58–0.61)[7]	0.70 (0.68–0.72)[7]	0.58 (0.55–0.61)	0.68 (0.66–0.71)[7]
Waist-hip ratio	0.87 (0.86–0.88)	0.53 (0.51–0.54)	0.64 (0.61–0.66)	0.58 (0.55–0.61)	0.62 (0.59–0.65)
Normal group					
BMI percentile	0.85 (0.82–0.87)[2,3]	0.53 (0.51–0.54)[2]	0.60 (0.56–0.63)[4]	0.52 (0.48–0.56)	0.58 (0.54–0.62)
WC percentile	0.99 (0.99–0.99)[5,6]	0.54 (0.52–0.56)[5]	0.59 (0.55–0.62)[6]	0.52 (0.48–0.56)	0.58 (0.53–0.62)
Waist-height ratio	0.95 (0.94–0.96)[7]	0.52 (0.50–0.54)	0.58 (0.55–0.61)[7]	0.51 (0.47–0.55)	0.51 (0.46–0.55)
Waist-hip ratio	0.86 (0.85–0.88)	0.55 (0.53–0.57)	0.50 (0.46–0.54)	0.54 (0.50–0.58)	0.52 (0.48–0.56)
Overweight group					
BMI percentile	0.75 (0.72–0.77)[2,3,8]	0.57 (0.54–0.61)[2,4,8]	0.59 (0.54–0.63)	0.54 (0.46–0.61)	0.52 (0.46–0.57)
WC percentile	0.94 (0.93–0.95)[5,6,8]	0.61 (0.58–0.65)[5,6,8]	0.58 (0.54–0.63)	0.56 (0.49–0.63)	0.51 (0.46–0.56)
Waist-height ratio	0.82 (0.80–0.84)[7,8]	0.58 (0.55–0.61)[7,8]	0.57 (0.52–0.61)	0.53 (0.46–0.60)	0.54 (0.49–0.60)
Waist-hip ratio	0.74 (0.72–0.77)[8]	0.52 (0.49–0.56)	0.56 (0.51–0.62)[8]	0.51 (0.44–0.58)	0.56 (0.50–0.61)
Obese group					
BMI percentile	0.78 (0.70–0.85)[2,3]	0.61 (0.57–0.64)[2,4,9]	0.61 (0.56–0.65)	0.51 (0.44–0.58)	0.61 (0.56–0.66)
WC percentile	0.93 (0.90–0.96)[5,6,9]	0.65 (0.62–0.69)[5,6,9]	0.61 (0.57–0.65)	0.50 (0.43–0.57)	0.64 (0.60–0.69)[5,6,9]
Waist-height ratio	0.88 (0.84–0.92)[7,9]	0.60 (0.56–0.63)[7,9]	0.60 (0.56–0.65)	0.52 (0.46–0.59)[7]	0.59 (0.54–0.64)[9]
Waist-hip ratio	0.83 (0.77–0.88)	0.54 (0.51–0.58)	0.58 (0.53–0.62)[9]	0.58 (0.51–0.65)	0.56 (0.51–0.61)

Note. [1]Abbreviations: AUC: area under receiver operating characteristic curve; BMI: body mass index; BP: blood pressure; HDL: high density lipoprotein; MetS: metabolic syndrome; TG: triglyceride; WC: waist circumference. [2]Significant difference in the AUCs of BMI percentile and WC percentile ($P < 0.05$). [3]Significant difference in the AUCs of BMI percentile and waist-height ratio ($P < 0.05$). [4]Significant difference in the AUCs of BMI percentile and waist-hip ratio ($P < 0.05$). [5]Significant difference in the AUCs of WC percentile and waist-height ratio ($P < 0.05$). [6]Significant difference in the AUCs of WC percentile and waist-hip ratio ($P < 0.05$). [7]Significant difference in the AUCs of waist-height ratio and waist-hip ratio ($P < 0.05$). [8]Significant difference in AUCs between the normal and overweight groups ($P < 0.05$). [9]Significant difference in AUCs between the normal and obese groups ($P < 0.05$).

0.57–0.57, respectively[30]. Although visceral fat content is thought to be the primary cause of metabolic disorders[31,32], anthropometric indices are indirect indicators for body weight or fat, which may limit the predictive accuracy[33-35]. The poor predictive performance for MetS components may be explained by multiple factors related to serum lipid level, fasting glucose level, and blood pressure, such as genetic polymorphism and dietary patterns.

We also found that compared to other indices, waist circumference percentile had a relatively better predictive performance for MetS regardless of BMI category. The superiority of waist circumference percentile for predicting MetS agreed with the conclusion of Perona et al. that waist circumference was the strongest anthropometric discriminators of MetS in Spanish adolescents among a list of 10 classic and novel anthropometric indices such as BMI, waist circumference, waist-height ratio, waist-hip ratio, and body fat percentage[29]. Some studies, however, reported different findings. One study in Brazil reported that waist-height ratio had the best AUC for MetS among BMI, waist circumference, waist-height ratio, and conicity index regardless of sex and age[36]. A national study in Korean children and adolescents showed that the AUCs for MetS and its components were similar for BMI percentile, waist circumference percentile, and waist-height ratio[28]. The predictive performance may vary across populations with different age, sex, and ethnicity[37]. These inconsistent results may be attributed to the different criteria used to define MetS and various combinations of anthropometric indices evaluated in different studies. In the present study, we used age- and sex-specific percentiles for BMI and waist circumference instead of actual values, which considers the impact of growth and sexual development.

The present study has several limitations that should be addressed. First, school-based sampling and the absence of final year students may weaken the representativeness of the adolescent population, especially for out-of-school adolescents. Second, we did not include participants in the pubertal stage, which has shown to be an important factor in MetS and should be considered in future studies[38,39]. Third, our study was cross-sectional in design; thus, data regarding the duration of obesity and recent changes in body weight were unavailable, which may help to better predict MetS[40]. We were also unable to evaluate prediction accuracy over time. As previous studies have suggested the instability of diagnosing MetS among adolescents over time[41], more prospective cohort studies are needed to investigate the association between adiposity-related anthropometric indices and MetS.

CONCLUSIONS

Despite the limitations, this study compared the discriminatory ability of four commonly used anthropometric indices, namely BMI percentile, waist circumference percentile, waist-height ratio, and waist-hip ratio, for MetS in adolescents with different nutritional status based on a multicenter study in China. All anthropometric indices, especially waist circumference percentile, showed a good prediction for MetS in the total sample and subjects with normal weight, while poor predictive results were observed for subjects with overweight and obesity. These findings may provide evidence for the use of anthropometric indices in youths with different BMI categories. Anthropometric indices, especially waist circumference percentile, can be used as an early screening tool for MetS in Chinese adolescents, while more specific tests should be conducted among adolescents who are overweight and obese.

ACKNOWLEDGMENTS

We also acknowledge the support from all the team members and the participating students, teachers, parents, and local education and health staffs.

AUTHOR CONTRIBUTIONS

The authors' contributions were as follows: LI Ya Mei, data analysis and manuscript drafting; ZOU Zhi Yong, data curation and manuscript drafting; MA Ying Hua, funding acquisition, project design and organization; LUO Jia You, JING Jin, ZHANG Xin, LUO Chun Yan, WANG Hong, ZHAO Hai Ping, and PAN De Hong, project design, investigation and quality control; LUO Mi Yang, study design and manuscript editing.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

Received: October 14, 2020;
Accepted: June 21, 2021

REFERENCES

1. Alberti KGMM, Zimmet P, Shaw J. Metabolic syndrome--a new world-wide definition. A Consensus Statement from the International Diabetes Federation. Diabet Med, 2006; 23, 469−80.
2. Zimmet P, Alberti G, Kaufman F, et al. The metabolic syndrome in children and adolescents. Lancet, 2007; 369, 2059−61.
3. Saklayen MG. The global epidemic of the metabolic syndrome. Curr Hypertens Rep, 2018; 20, 12.
4. Daniels SR. Complications of obesity in children and adolescents. Int J Obes (Lond), 2009; 33 Suppl 1, S60−5.
5. Franks PW, Hanson RL, Knowler WC, et al. Childhood obesity, other cardiovascular risk factors, and premature death. N Engl J Med, 2010; 362, 485−93.
6. Morrison JA, Friedman LA, Wang P, et al. Metabolic syndrome in childhood predicts adult metabolic syndrome and type 2 diabetes mellitus 25 to 30 years later. J Pediatr, 2008; 152, 201−6.
7. Morrison JA, Friedman LA, Gray-McGuire C. Metabolic syndrome in childhood predicts adult cardiovascular disease 25 years later: the Princeton Lipid Research Clinics Follow-up Study. Pediatrics, 2007; 120, 340−5.
8. Hosseini-Esfahani F, Bahadoran Z, Moslehi N, et al. Metabolic syndrome: findings from 20 years of the tehran lipid and glucose study. Int J Endocrinol Metab, 2018; 16, e84771.
9. Perona JS, Schmidt-RioValle J, Rueda-Medina B, et al. Waist circumference shows the highest predictive value for metabolic syndrome, and waist-to-hip ratio for its components, in Spanish adolescents. Nutr Res, 2017; 45, 38−45.
10. Zhou D, Yang M, Yuan ZP, et al. Waist-to-Height Ratio: a simple, effective and practical screening tool for childhood obesity and metabolic syndrome. Prev Med, 2014; 67, 35−40.
11. Viggiano D, De Filippo G, Rendina D, et al. Screening of metabolic syndrome in obese children: a primary care concern. J Pediatr Gastroenterol Nutr, 2009; 49, 329−34.
12. Matsha TE, Kengne AP, Yako YY, et al. Optimal waist-to-height ratio values for cardiometabolic risk screening in an ethnically diverse sample of South African urban and rural school boys and girls. PLoS One, 2013; 8, e71133.
13. Rodea-Montero ER, Evia-Viscarra ML, Apolinar-Jiménez E. Waist-to-height ratio is a better anthropometric index than waist circumference and BMI in predicting metabolic syndrome among obese mexican adolescents. Int J Endocrinol, 2014; 2014, 195407.
14. Hai AA, Iftikhar S, Latif S, et al. Prevalence of metabolic syndrome in overweight and obese patients and their measurement of neck circumference: a cross-sectional study. Cureus, 2019; 11, e6114.
15. Ärnlöv J, Ingelsson E, Sundström J, et al. Impact of body mass index and the metabolic syndrome on the risk of cardiovascular disease and death in middle-aged men. Circulation, 2010; 121, 230−6.
16. Arnlöv J, Sundström J, Ingelsson E, et al. Impact of BMI and the metabolic syndrome on the risk of diabetes in middle-aged men. Diabetes Care, 2011; 34, 61−5.
17. Ministry of Education of the People's Republic of China. China education yearbook (2014). http://www.moe.gov.cn/jyb_sjzl/moe_364/zgjynj_2014/. (In Chinese)
18. Chen YJ, Ma L, Ma YH, et al. A national school-based health lifestyles interventions among Chinese children and adolescents against obesity: rationale, design and methodology of a randomized controlled trial in China. BMC Public Health, 2015; 15, 210.
19. Dong B, Dong YH, Yang ZG, et al. Healthy body weight may modify effect of abnormal birth weight on metabolic syndrome in adolescents. Obesity (Silver Spring), 2019; 27, 462−9.
20. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. Pediatrics, 2004; 114, 555−76.
21. Li H, Ji CY, Zong XN, et al. Body mass index growth curves for Chinese children and adolescents aged 0 to 18 years. Chin J Pediatr, 2009; 47, 493−8. (In Chinese)
22. Ji CY, Yt Sung R, Ma GS, et al. Waist circumference distribution of Chinese school-age children and adolescents. Biomed Environ Sci, 2010; 23, 12−20.
23. Hosmer DW, Lemeshow S, Sturdivant RX. Applied logistic regression. 3rd ed. John Wiley & Sons Inc.. 2013.
24. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics, 1988; 44, 837−45.
25. Cheng H, Chen FF, Ye PY, et al. Characteristics of cardiometabolic risk factors of children and adolescents aged 6-17 years in seven cities in China from 2013 to 2015. Chin J Prev Med, 2018; 52, 1130−5. (In Chinese)
26. Morandi A, del Giudice EM, Martino F, et al. Anthropometric indices are not satisfactory predictors of metabolic comorbidities in obese children and adolescents. J Pediatr, 2014; 165, 1178−83.e2.
27. Khoury M, Manlhiot C, McCrindle BW. Role of the waist/height ratio in the cardiometabolic risk assessment of children classified by body mass index. J Am Coll Cardiol, 2013; 62, 742−51.
28. Choi DH, Hur YI, Kang JH, et al. Usefulness of the waist circumference-to-height ratio in screening for obesity and metabolic syndrome among korean children and adolescents: korea national health and nutrition examination survey, 2010-2014. Nutrients, 2017; 9, 256.
29. Perona JS, Rio-Valle JS, Ramírez-Vélez R, et al. Waist circumference and abdominal volume index are the strongest anthropometric discriminators of metabolic syndrome in Spanish adolescents. Eur J Clin Invest, 2019; 49, e13060.
30. Himes RW, Barlow SE, Bove K, et al. Lysosomal acid lipase deficiency unmasked in two children with nonalcoholic fatty liver disease. Pediatrics, 2016; 138, e20160214.
31. Daniels SR, Morrison JA, Sprecher DL, et al. Association of body fat distribution and cardiovascular risk factors in children and adolescents. Circulation, 1999; 99, 541−5.
32. Bosch TA, Dengel DR, Kelly AS, et al. Visceral adipose tissue measured by DXA correlates with measurement by CT and is associated with cardiometabolic risk factors in children. Pediatr Obes, 2015; 10, 172−9.
33. Bigornia SJ, LaValley MP, Benfield LL, et al. Relationships between direct and indirect measures of central and total adiposity in children: what are we measuring? Obesity (Silver Spring), 2013; 21, 2055−62.
34. Goodwin K, Syme C, Abrahamowicz M, et al. Routine clinical measures of adiposity as predictors of visceral fat in adolescence: a population-based magnetic resonance imaging study. PLoS One, 2013; 8, e79896.
35. Hajian-Tilaki K, Heidari B. Prevalences of overweight and obesity and their association with physical activity pattern among Iranian adolescents aged 12-17 years. Public Health Nutr, 2012; 15, 2246−52.
36. de Oliveira RG, Guedes DP. Performance of anthropometric indicators as predictors of metabolic syndrome in Brazilian

adolescents. BMC Pediatr, 2018; 18, 33.
37. Freedman DS, Serdula MK, Srinivasan SR, et al. Relation of circumferences and skinfold thicknesses to lipid and insulin concentrations in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr, 1999; 69, 308−17.
38. Cardenas-Vargas E, Nava JA, Garza-Veloz I, et al. The influence of obesity on puberty and insulin resistance in mexican children. Int J Endocrinol, 2018; 2018, 7067292.
39. Lian QG, Mao YY, Luo S, et al. Puberty timing associated with obesity and central obesity in Chinese Han girls. BMC Pediatr, 2019; 19, 1.
40. Lawlor DA, Benfield L, Logue J, et al. Association between general and central adiposity in childhood, and change in these, with cardiovascular risk factors in adolescence: prospective cohort study. BMJ, 2010; 341, c6224.
41. Goodman E, Daniels SR, Meigs JB, et al. Instability in the diagnosis of metabolic syndrome in adolescents. Circulation, 2007; 115, 2316−22.