Waist circumference and abdominal volume index are the strongest anthropometric discriminators of metabolic syndrome in Spanish adolescents

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Abstract

Background: Waist circumference has been suggested as predictor for metabolic syndrome (MetS) in adolescents but it has not been compared with newly proposed anthropometric indexes. This study aimed to disclose the capacity of ten classic and novel anthropometric indexes to discriminate by the presence of MetS in this young population.

Materials and methods: A cross-sectional study was performed on 981 adolescents (13.2 ± 1.2 y) randomly recruited from eighteen schools in south-east Spain. Body fat percentage (BF%), abdominal volume index (AVI), body roundness index (BRI), body mass index (BMI), body adiposity index (BAI), body adiposity index for pediatrics (BAIp), conicity index (C-Index), waist circumference (WC), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR) and body shape index (ABSI) were measured and calculated. Receiver-operator curves (ROC) were created to determine the discriminatory capacity of these anthropometric parameters for MetS.

Results: The prevalence of MetS was 7.0% for boys and 6.1% in girls. Participants with MetS had significantly higher levels of blood pressure and plasma levels of lipids, glucose and insulin. All anthropometric indexes were elevated in MetS individuals compared to the non-MetS group. AVI and WC showed the highest AUC values (0.83 for boys and 0.86 for girls). In contrast, according to ROC analyses, no anthropometric index was capable of discriminating the components of MetS (hypertension, hypertriglyceridemia, hyperglycemia and low HDL levels), except for abdominal obesity.

Conclusion: We suggest the use of WC and AVI, with the cutoff points presented herein, for the discrimination between adolescents with or without MetS.

Keywords: Anthropometric indexes; Metabolic syndrome; Obesity; Adolescents.

1. Introduction

Metabolic syndrome (MetS), as a cluster of risk factors for cardiovascular morbidity and mortality, has become a major health concern in both developing and developed countries, whose prevalence in adolescents is increasing worldwide.¹ Indeed, Miller et al.² described that approximately 73.2% of participants in their study presented at least one component risk factor, and found a prevalence of MetS of 10.1% in American children and adolescents.

MetS increases the risk of developing metabolic diseases,³ as just like in adults, in adolescents with MetS there is a higher risk of developing insulin resistance, low-grade chronic inflammation⁴ and oxidative stress,⁵ (Bonomini et al., 2015). This condition also favors the early development of coronary heart disease (CHD).⁶

Therefore, the need of early identification of MetS, emphasizes the importance of the determination of the anthropometric indexes with a highest predictive capacity for MetS. Body mass index (BMI) is widely used to assess the nutritional status of adults and infants.⁷ However, BMI does not allow to discern the organic distribution of adipose tissue. A growing body of evidence supports the hypothesis that abdominal fat plays a role in the development of MetS.⁸ Therefore, new anthropometric indexes are need to assess the abdominal fat depot. In this regard, Krakauer et al.⁹ and Tomas et al.¹⁰ proposed a body shape index (ABSI) and body roundness index (BRI), respectively, to estimate body fat distributions. However, neither ABSI nor BRI have been shown to correlate with MetS more strongly than WC.¹¹ On the other hand, WC has been questioned for not considering height and hip circumference, and thus the waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR) emerged as parameters of clinical interest to evaluate adiposity and predict the cardiovascular risk. However, whereas WHtR has revealed as a potent marker of MetS in childhood,¹² inconclusive results were obtained for WHR.¹³

Other anthropometric indexes employed in the clinical practice are the percentage of body fat (BF%), as measured by electric bioimpedance, the body adiposity index (BAI) which was proposed by Bergman et al.¹⁴, and more recently, BAI for pediatrics (BAIp) proposed by Aarbaoui et al.¹⁵. The latter index was developed for the specific use in infant populations but there are no conclusive results for it so far.¹⁶ Likewise, abdominal volume index (AVI) and conicity index (C-Index), are other anthropometric indexes, whose predictive capacity against MetS in adolescents is still controversial.^{17,18} On the basis of the scarce information that has been reported on the use of these indexes in adolescents, this study aimed to disclose their capacity to discriminate for MetS in Spanish adolescents compared to classic ones.

2. Methods and materials

2.1 Study design and sample

The present is a cross-sectional study whose sample population consisted of 981 adolescents (456 boys and 525 girls), 13.2 ± 1.2 years of age (11-16 years old), all of Spanish origin and similar socioeconomic status. The subjects attended 18 high-schools in the provinces of Granada and Almeria (South-East of Spain) (10 public and 8 private). A letter of invitation was sent to the school principals and all centers agreed to participate in the study. Of the 18 schools, two classes per grade of a total of three were randomly selected and invited to participate in the study. The flow diagram (Fig. 1) summarizes the process of selecting participants. The study was previously approved by the Board of Education of the Andalusian Regional Government (Granada and Almeria Delegations), and also authorized by the school principals. The study, including the model of informed consent used, was approved by the Ethics Committee of the University of Granada. At the beginning of the study, an informed consent was obtained from the subjects' parents or guardians. This research was performed in

strict compliance with the International Code of Medical Ethics established by the World Medical Association and the Declaration of Helsinki. An important condition for inclusion in the study was that subjects had to be healthy and not have any type of endocrine dysfunction or physical disorder. All students who did not meet these criteria were not candidates to participate in the study.

2.2 Anthropometric measurements

Each participant underwent an anthropometric evaluation performed by a Level 2 anthropometrist certified by the International Society for the Advancement of Kinanthropometry (ISAK), in accordance with the ISAK guidelines.¹⁹ We performed the anthropometric measurements in the morning after a 12-hr fast and a 24-hr abstention from exercise. We measured body weight (kg) twice (with participants wearing no shoes and in light clothes) using a self-calibrating Seca1 861 class (III) digital floor scale (Saint Paul, USA) with a precision of up to 100 g. We measured height with a Seca 214* portable stadiometer, asking participants to remove their shoes and stand erect with their backs, buttocks, and heels in continuous contact with the vertical height rod of the stadiometer and head oriented in the Frankfurt plane. We then placed the horizontal headpiece on top of the participants' heads to measure their height. We took height measurements twice to the nearest 0.5 cm. We used the average of the two values for weight and height in the analysis. A trained member of the research team collected anthropometric measures and blood pressure in a classroom enabled for this purpose by the principal of each school. We defined overweight and obesity, according to the international standards established by Cole et al.²⁰, as values above the 85th and 95th percentiles, respectively, for BMI for age and sex.

2.3 Calculation of anthropometric indexes

We calculated BMI as weight divided by height squared (kg/m^2) and we measured WC with a Seca automatic roll-up measuring tape (precision of 1 mm) using the horizontal plane midway between the lowest rib and the upper border of the iliac crest at the end of a normal inspiration/expiration. Hip circumference was measured at the maximum extension of the buttocks as viewed from the right side. WHR and WHtR were consequently calculated by dividing the WC by the hip circumference and the height, respectively. We determined BF% using bioelectrical impedance analyses (BIA) by whole-body impedance (Tanita Model BC-418®, Tokyo, Japan). Detailed information about the BIA technique has been provided in previous studies.²¹

The rest anthropometric indexes (AVI, BRI, BAI, BAIP, C-Index, and ABSI) were calculated using the following formulas:

$$\mathbf{AVI} = [2\text{Waist Circunference}^2 (\text{cm}) + 0.7(\text{Waist Circunference} - \text{Hip Circunference})^2 (\text{cm})] / 1000 \text{ (Guerrero-Romero et al.}^{17}\text{)}$$

$$\mathbf{BRI} = 364.2 - 365.5 [1 - \pi^{-2} \text{Waist Circunference}^2 (\text{m}) \text{Height}^{-2} (\text{m})]^{1/2} \text{ (Thomas et al.}^{10}\text{)}$$

$$\mathbf{BAI} = [\text{Hip circumference (m)} / \text{Height}^{2/3} (\text{m})] - 18 \text{ (Bergman et al.}^{14}\text{)}$$

$$\mathbf{BAIP} = \text{Hip circumference (cm)} / \text{height (m)}^{0.8} - 38 \text{ (El Aarbaoui et al.}^{15}\text{)}$$

$$\mathbf{C-Index} = 0.109^{-1} \text{Waist Circunference (m)} [\text{Weight (kg)} / \text{Height (m)}]^{-1/2} \text{ (Valdez}^{22}\text{)}$$

$$\mathbf{ABSI} = \text{WC (m)} / [\text{BMI}^{2/3} (\text{kg/m}^2) \text{Height}^{1/2} (\text{m})] \text{ (Krakauer et al.}^{9}\text{)}$$

2.4 Serum Biochemical Examination

At 8:00 A.M. after a 12-hour overnight fast, 10 ml of blood was extracted by venipuncture in the antecubital fossa of the right arm with a disposable vacuum blood collection tube. In the four hours after the extraction, all samples were centrifuged at 1300g for 15 minutes (Z400 K, Hermle, Wehingen, Germany). The red blood cells were thus separated and the serum was finally frozen at -80°C for its subsequent analysis. Immediately after collection and before centrifugation, however, we measured glucose concentration using an enzymatic colorimetric method (glucose oxidase-phenolaminophenazone [GOD-PAP] method, Human Diagnostics, Germany) as well as the concentrations of HDL-C, total cholesterol, and triglycerides by means of enzymatic colorimetric methods using an Olympus analyzer. Low-density lipoprotein-cholesterol (LDL-C) was estimated using the Friedewald equation ($[\text{LDL-C}] = [\text{Total Cholesterol}] - [\text{HDL-C}] - ([\text{TG}] / 5)$), where TG = concentration of triglycerides. Serum insulin was determined by radioimmunoanalysis (Insulin Kit, DPC, Los Angeles, EEUU). Insulin resistance was quantified with HOMA (Homeostasis Model Assessment)²³ by applying the following formula: fasting glucose (mmol/L) x fasting insulin (mU/L)/22.5.

2.5 Blood Pressure determination

We measured blood pressure (BP) levels using a previously calibrated aneroid sphygmomanometer and a Littmann® stethoscope (Saint Paul, USA), following the recommendations for blood pressure measurement of the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research.²⁴ Systolic BP $\geq$ 130 and/or diastolic BP $\geq$ 85 mmHg were regarded as a risk factor of MetS.

2.6 Diagnostic criteria of metabolic syndrome according to the International Diabetes Federation, IDF

According to the International Diabetes Federation (IDF), MetS was diagnosed in adolescent subjects when the following criteria were fulfilled: a waist circumference ≥ 94 cm in boys and ≥ 80 cm in girls, together with two more of the following risk factors: fasting blood glucose levels 100–125 mg/dl, serum triglyceride levels ≥ 150 mg/dl, HDL-cholesterol levels < 40 mg/dl in boys and $<$ than 50 mg/dl in girls, and blood pressure $\geq 130/85$ mmHg.²⁵ Therefore, adolescents who met the above mentioned criteria were classified as MetS and those not meeting the criteria as Non-MetS.

2.7 Statistical analysis

The Kolmogorov-Smirnov test was used to assess the normality of the distribution. Results were reported as mean $\pm$ SD, except for the number of girls and boys with or without MetS, which was expressed as number and percentage. Differences between subjects with or without MetS were assessed using a t-test, Mann-Whitney's test or chi-square test as appropriate. The area under receiver operating characteristic (ROC) curves was calculated to evaluate the abilities of the anthropometric indices to discriminate for MetS and its components (abdominal obesity, hypertriglyceridemia, hypertension, hyperglycemia and low HDL-cholesterol). Cutoff points were proposed after calculation of the Youden's Index (sensitivity+specificity-1). DeLong et al.'s²⁶ non-parametric approach was used to compare the areas under the ROC curves. Since abdominal obesity is a component of MetS, we conducted a multicollinearity test for the anthropometric indexes that included WC (AVI, BRI, C-Index and ABSI) and the variance inflation factor (VIF) was calculated. Statistical analyses were performed using

SPSS v24.0 (IBM, Armonk, USA). MedCalc v18,2,1, (MedCalc Software, Ostend, Belgium) was used to analyze the ROC curves. Statistical significance was defined as $p < 0.05$.

3. Results

3.1 Baseline characteristics of the participants

Among the 456 boys and 525 girls recruited for the study, 7.0% of boys and 6.1% of girls presented MetS. Age was slightly different between girls with or without MetS. Compared with the non-MetS group, participants with MetS had significantly higher levels of SBP, DBP, HbA1c, insulin, TG, HOMA-IR, fasting NEFA, FG, cholesterol, LDL-cholesterol and HDL-cholesterol both in boys and girls. In contrast, no significant difference was observed for between MetS and non-MetS participants. All anthropometric indexes (WC, BMI, WHR, WHtR, AVI, BAI, BAIp, BRI and C-Index), as well as BF %, were elevated in MS individuals compared to the non-MS group. ABSI was only significantly higher in boys with MetS compared to non-MetS (Table 1).

3.2 AUC values of the anthropometric indexes for the diagnosis of MetS

AUC values obtained from ROC analysis of all the anthropometric indexes, except for ABSI, were higher than 0.7 (asymptotic significance $p < 0.05$) in boys (Table 2) and girls (Table 3), which suggests that they are all good markers of MetS. Our results showed that AVI and WC indexes had the highest AUC values (0.83 in both boys and 0.86 girls) and were not significantly different between them. For AVI, the cutoff point for the diagnosis of MetS was 10.52 for boys and 10.89 for girls, and for WC the cutoff point was 75.00 for boys and 72.00 for girls. The lowest AUC values were observed for ABSI. For boys, AUC values of this index were 0.66 (0.58-0.74) and for girls it was 0.58 (0.49-0.67). AUC values obtained for BAIp

resulted to be slightly higher compared to BAI in both boys (0.75 vs 0.68) and girls (0.84 vs 0.79). AUC values of all anthropometric indexes except for AVI and WHR were significantly different compared to WC in boys ($p < 0.05$) and AVI, BAIP and BRI in girls ($p < 0.05$).

3.3 AUC values of the anthropometric indexes for discriminating MetS components

Table 4 and 5 show the results of the ROC analysis for the anthropometric indexes as predictors of the components of MetS: abdominal obesity, hipertriglyceridemia, hyperglycemia, hypertension and low-HDL-cholesterol. Abdominal obesity was clearly discriminated by AVI and WC, with AUC values of 1.00 in both girls and boys. BAIP, BMI, WHtR and BRI also showed a high capacity for discriminating for abdominal obesity in both groups, showing AUC values above 0.90, while AUC values for BAI, C-Index and BF % were above 0.80 but below 0.90. For hypertension, AUC values were mostly in the range of 0.7-0.8 in boys and girls, except for ABSI, C-Index, and WHR. The highest AUC values observed corresponded to AVI, BMI and WC (0.77 in boys for the three indexes and between 0.75-0.79 in girls). None of the anthropometric indexes were able to discriminate for the presence of the rest of the components of MetS. For hipertriglyceridemia, hyperglycemia and low HDL-cholesterol, AUC values were lower than 0.63 of all indexes and both groups.

4. Discussion

The results obtained show a relatively high prevalence of MetS in the population studies, particularly in male subjects (7%). In fact, our results are higher than those obtained by others using the definition of MetS of the IDF²⁵, Park et al.²⁷, in a study with 734 American and 664 Korean adolescents, described a prevalence of MetS of 5.5% and 2.5%, respectively. On the other hand, in another Spanish population of 362 adolescents, González et al.²⁸, showed a prevalence of 10.5% in males and 2.7% in females. Differences in prevalence should be

interpreted with caution, as they can be explained by the use of different criteria to define MetS, as well as by differences in sample size. In any case, these results reflect a high prevalence of MetS among the Spanish youth population.

In our study, the group of adolescents with MetS (boys and girls) showed considerably higher values of SBP, DBP, HbA1c, insulin, TG, HOMA-IR, fasting NEFA, FG, total cholesterol, LDL-cholesterol and lower HDL-cholesterol, compared to the group without MetS. These results are similar to those reported by Johnson et al.³, who in a population of 2456 American adolescents of both sexes and with MetS, described a cardiometabolic profile similar to that found in our participants. In this regard, cardiometabolic imbalances at early ages are worrisome, as they can represent the initiation of the atherosclerotic process that is determinant for the development of cardiovascular diseases.²⁹

On the other hand, all the parameters and anthropometric indexes analyzed in this study (WC, BMI, WHR, WHtR, AVI, BAI, BAIP, BRI and C-Index), as well as BF %, but not ABSI, showed higher values among the adolescents with MetS compared to the group without MetS. These results are in agreement with those reported by Pereira et al.³⁰ and Teixeira et al.³¹ in Brazilian adolescents, who found higher WC, BMI and WHR values among subjects with MetS, as well as with those reported by Zhou et al.³² for WHtR in 16,914 Chinese children and adolescents. These results highlight the importance of the distribution of the fatty tissue in the organism and its close relationship with the development of metabolic and cardiovascular disorders at an early age.³³

In regard to the potential discriminatory capacity for MetS of the anthropometric indexes studied, the ROC analysis showed that all indexes, except ABSI, were capable of discriminating subjects with MetS, showing AUC scores higher than 0.7 in both sexes. According to Liu et al.³⁴, the existence of a strong association between visceral obesity,

insulin resistance and dyslipidemia, allows to suppose in these anthropometric indexes a discriminatory capacity against MetS. In this sense, in a previous study, AVI showed a strong association with impaired glucose tolerance and type 2 diabetes mellitus.¹⁷ In our study, AVI and WC showed the highest values of AUC, particularly in girls (0.867 for AVI and WC) compared to boys (0.831 for both parameters). Therefore, AVI and WC are the anthropometric indexes that best discriminated for MetS in the population of adolescents studied. According to Mamtani & Kulkarni³⁵ and Mehta et al.³⁶, this observation could be explained by the high capacity that have these individual indexes to discriminate the abdominal fat as a main component of the MetS, compared to the rest of the indicators used. However, these results differ partially from those obtained by Motamed et al.³⁷, for AVI in subjects from Northern Iran, who presented AUC values of 0.72 in males and 0.73 in females. In the case of WC, their values for both sexes (0.71 boys and 0.73 girls) were also lower than those obtained in our study. In our opinion, these differences in results between the studies can be attributed to differences in anthropometric properties of various ethnic groups.

WHtR is regarded as one of the most potent markers of cardiometabolic risk in children and adolescents. In fact, Ochoa-Sangrador and Ochoa-Brezmes¹² concluded that WHtR should be measured in regular health checks in this population, as it can measure cardiovascular risk regardless of the degree of general obesity. In their meta-analysis of 31 studies, these authors showed a pooled AUC of 0.76 for boys and girls for MetS, which is slightly lower than the AUC observed in the present study. However, most of the analyzed studies of a sample size similar or larger to ours did not provide ROC calculations. Among those that did perform ROC analyses, Maffei et al.³⁸, in Italian children and Zhou et al.³², in Chinese children, reported AUC values between 0.8 and 0.9 and cut-off points between 0.47 and 0.50, which are coherent with our results. In contrast, in a mixed race South African population, Matsha et al.³⁹ showed AUC values below 0.7.

On the other hand, BAIP shows slightly higher AUC values in comparison to BAI in both sexes, (boys (0.75 vs 0.68) and girls (0.84-0.79)), which suggests a better discriminatory capacity. These results are in agreement with those described by El Aarbaoui et al.¹⁵, who concluded that BAI overestimates the BF% in adolescents. Therefore, BAIP would be a more accurate and reliable index, and valid as predictor of MetS in the juvenile population. Our results also showed that BMI has higher AUC values in both sexes than both the BAI and BAIP, indicating an adequate discriminatory capacity between MetS and non-MetS, especially among girls. These results are consistent with what was described by Thivel et al.¹⁶, who concluded that BMI is a more accurate adiposity estimator than BAIP in adolescents, being therefore more useful for predicting alterations such as MetS in the adolescent population. BRI had a good discriminatory capacity in the diagnosis of MetS in girls and thus may be considered, together with AVI and WC, as an appropriate index for the diagnosis of MetS. To our knowledge, this predictive capacity of BRI has been described previously in studies with adult populations only.⁴⁰ According to our results, we propose the use of BRI primarily in adolescent girls in the discrimination of MetS as an alternative anthropometric index. On the other hand, the ABSI showed the lowest AUC values in our study. Consequently, and in line with previous studies in adults^{41,42}, ABSI should not be used as a predictive index for MetS in adolescents of both genders. Since WC is used as a component of the MetS, we performed a collinearity test for all anthropometric indexes that included WC for their calculation. The results of the test showed to be negative for WC and AVI ($VIF < 3$) and positive for C-Index, BRI and ABSI ($VIF > 3$).

The ROC analysis for the discrimination of the MetS components, indicated that AVI and WC are powerful predictors of abdominal obesity, with AUC values of 1.00 in both sexes. These results agree with those of Wang et al.⁴³, who despite obtaining values of AUC lower than 1, concluded that AVI and WC are the anthropometric indexes that best discriminate for

abdominal obesity. BAIP, BMI, WHtR and BRI also showed a high capacity to discriminate for abdominal obesity in both groups, with AUC values higher than 0.90. In fact, Thomas et al.¹⁰, proposed that BRI allows an accurate estimation of the body adipose tissue, being a reliable predictor of abdominal obesity.

On the other hand, Al-Bachir et al.⁴⁴, in their study with a Syrian adolescent population, concluded that BMI, despite showing values of AUC lower than those obtained in our study, is still a powerful discriminator for abdominal obesity. In regard to C-Index, in our study, this index resulted to be a less reliable discriminator for abdominal obesity than AVI, WC, BMI and BRI. In agreement, Taylor et al.⁴⁵, in their study with 187 Brazilian schoolchildren, also concluded that C-Index is a less accurate discriminator for abdominal obesity than WC. Since C-Index was created for use in adult subjects, according to Andaki et al.⁴⁶, their ability in young subjects to assess abdominal obesity as an essential component of MetS could be limited.

For the component hypertension, AVI, BMI and WC showed the highest AUC values (0.77 in boys for the three indexes and 0.75-0.79 among girls). Similarly, Wang et al.⁴³, showed that these indexes presented the highest AUC values for hypertension in adults males. In contrast, Duncan et al.⁴⁷, in their study of 445 Portuguese adolescents (10 to 17 years) concluded that ABSI has a superior capacity compared to WC and BMI for the prediction of hypertension. This finding indicates the existence of important discrepancies regarding the discriminatory capacity of these anthropometric indexes. On the other hand, the ABSI, BAI, BAIP, BRI, C-Index, BF %, and WHR indices did not show discriminatory capacity in both sexes for the other MetS components studied (hypertriglyceridemia, hyperglycemia and low HDL-cholesterol).

The present study has some strengths and limitations. Among the strengths, we would like to emphasize the large sample size, which contributes to obtaining solid results that will be useful and will improve comparability in future studies. The recruitment was designed to select a representative sample of the entire population for the age groups studied in the region, for which we consider that the study is of great importance in epidemiological terms. In addition, all participants belonged to the same geographical region, with similar culture, lifestyle and eating habits, making the sample more homogeneous. On the other hand, in order to determine the accuracy of the analysis for discriminating subjects with MS, we performed calculations of the following parameters: detection rate, false positive rate, positive likelihood ratio, negative likelihood ratio, positive predictive value, negative predictive value and effectiveness (Supplementary Tables 1 and 2). These parameters confirmed the robustness of the analysis. Among the limitations of the study, we must include the use of the IDF criteria only to define MetS. Therefore, we suggest that more studies are needed to determine if the results obtained are consistent under different criteria.

In conclusion, the results show that AVI and WC are the anthropometric indexes that best discriminate between MetS and non-MetS in the population of adolescents studied, especially in girls. In addition, AVI and WC showed an important discriminatory capacity for abdominal obesity in both sexes. These findings may be useful for guidelines of clinical practice and future research on prevention of MetS in adolescent populations. Clinical and public health authorities should consider these results to improve the procedures for the early detection of MetS in the young population. The discrepancies observed between our results and those of the authors justify the need to develop new studies with broader populations in order to explore in depth the predictive capacity of these anthropometric indexes.

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Disclosures

No conflict of interest, financial or otherwise is declared by the authors.

Author contributions

EGJ and JSP conceived and designed the study. MCR and AFA collected and analysed the data. JSR and RRV interpreted the data. EGJ and JSP drafted the manuscript. All authors have revised and approved the submitted manuscript.

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Figure Legend

Figure 1. Flow diagram of the recruitment progress.

Table 1. Baseline characteristics of participants according to the MetS status.

	Males (n=456)					Females (n=525)				
	Non MetS		MetS		p	Non MetS		MetS		p
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Number (%)	415	93.0	41	7.0	<0.001	493	93.9	32	6.1	<0.001
Age (y)	13.1	1.2	13.6	1.0	0.026	13.3	1.2	13.3	1.1	0.779
SBP (mmHg)	117.9	14.7	137.2	14.7	<0.001	115.9	14.8	132.3	10.2	<0.001
DBP (mmHg)	63.6	8.5	74.1	11.4	<0.001	63.5	8.6	70.7	8.8	<0.001
FG (mg/dL)	82.0	24.5	128.4	53.5	<0.001	82.1	23.6	132.0	52.2	<0.001
HBA1c (%)	4.7	2.3	6.0	2.3	0.001	4.5	1.1	6.1	2.2	<0.001
Insulin (mIU/L)	20.2	9.2	28.7	15.1	<0.001	19.4	7.7	32.5	15.8	<0.001
HOMA-IR	4.0	2.0	8.8	6.0	<0.001	3.9	1.7	11.0	8.0	<0.001
Cholesterol (mg/dL)	79.8	15.2	101.9	23.8	<0.001	79.8	14.0	106.3	20.0	<0.001
LDL (mg/dL)	89.8	18.6	129.6	35.6	<0.001	90.3	19.0	132.3	33.2	<0.001
HDL (mg/dL)	40.5	2.3	35.7	3.4	<0.001	40.3	2.9	35.3	2.6	<0.001
TG (mg/dL)	122.9	45.0	193.0	120.1	<0.001	120.3	31.6	196.2	120.9	<0.001
NEFA (fasting)	0.23	0.14	0.35	0.21	<0.001	0.22	0.12	0.45	0.23	<0.001
BF (%)	26.6	8.1	34.1	6.5	<0.001	29.1	7.6	38.1	6.6	<0.001
BMI (Kg/m ²)	21.1	3.7	25.2	4.3	<0.001	20.8	3.4	25.8	3.5	<0.001
WC (cm)	72.5	11.3	86.0	9.9	<0.001	70.5	9.2	83.2	7.5	<0.001
WHR	0.87	0.06	0.94	0.10	<0.001	0.85	0.06	0.88	0.05	0.001
WHtR	0.48	0.07	0.52	0.06	<0.001	0.45	0.06	0.52	0.06	<0.001
ABSI (m ^{7/6} /Kg ^{2/3})	0.075	0.006	0.076	0.005	0.001	0.075	0.005	0.075	0.004	0.295
BAI (0.01m ^{-0.5})	22.5	4.4	25.5	5.5	<0.001	23.9	3.9	28.2	3.7	<0.001
BAIp (0.01m ^{-0.5})	18.7	5.7	23.7	6.7	<0.001	19.6	5.2	26.4	4.7	<0.001
AVI (cm ²)	10.9	3.5	15.0	3.5	<0.001	10.2	2.7	14.1	2.5	<0.001
BRI	2.5	1.2	3.8	1.3	<0.001	2.5	1.0	3.7	1.0	<0.001
C-Index (m ^{2/3} /Kg ^{1/2})	1.14	0.10	1.23	0.08	<0.001	1.13	0.08	1.18	0.06	<0.001

Data were shown as mean $\pm$ SD. Differences of biochemical parameters between groups with or without MetS were compared using an independent t-test, Mann-Whitney test or Chi-square test, according to the characteristics of the data.

ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-Index, conicity index; DBP, diastolic blood pressure; BF, body fat content; FG, fasting glucose; HBA1c, glycosylated hemoglobin; HDL, high-density lipoprotein cholesterol; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoprotein cholesterol; MetS, metabolic syndrome; NEFA, non-esterified fatty acids; SBP, systolic blood pressure; TG, triglycerides; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 2. Area under the curve (AUC), optimal cutoff point, sensitivity, specificity, and Youden Index in receiver-operator curves (ROC) analysis of different anthropometric indexes for discriminating between MetS and non-MetS in boys.

	AUC	SD	95% CI	p	Cutoff	Sensitivity	Specificity	Youden Index
ABSI	0.66	0.04	0.58-0.74	<0.001	0.07	0.80	0.45	0.26
AVI	0.83	0.02	0.78-0.88	0.928	10.52	1.00	0.55	0.55
BAI	0.68	0.04	0.59-0.77	<0.001	24.85	0.61	0.71	0.32
BAIp	0.75	0.04	0.67-0.83	0.031	20.26	0.75	0.66	0.42
BMI	0.78	0.03	0.72-0.84	<0.001	21.43	0.85	0.60	0.45
BRI	0.80	0.03	0.74-0.86	0.076	2.57	0.85	0.68	0.53
C-Index	0.76	0.03	0.69-0.83	0.027	1.19	0.68	0.77	0.45
BF (%)	0.75	0.03	0.69-0.82	0.001	26.95	0.90	0.55	0.46
WC	0.83	0.02	0.78-0.88	1.000	75.00	1.00	0.75	0.57
WHR	0.78	0.03	0.73-0.84	0.069	0.86	0.92	0.59	0.52
WHtR	0.80	0.03	0.74-0.86	<0.001	0.47	0.85	0.68	0.53

DeLong et al.'s non-parametric approach was used to compare the AUCs of indices with WC. Youden Index was calculated as sensitivity + specificity – 1.

ABSI, a body shape index; AVI, abdominal volume index; AUC, area under the curve; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-Index, conicity index; BF, body fat content; MetS, metabolic syndrome; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 3. Area under the curve (AUC), optimal cutoff point, sensitivity, specificity, and Youden Index in receiver-operator curves (ROC) analysis of different anthropometric indexes for discriminating between MetS and non-MetS in girls.

	AUC	SD	95% CI	p	Cutoff	Sensitivity	Specificity	Youden Index
ABSI	0.58	0.04	0.49-0.67	<0.001	0.07	0.75	0.47	0.22
AVI	0.86	0.02	0.82-0.90	0.692	10.89	1.00	0.70	0.70
BAI	0.79	0.03	0.73-0.86	0.019	25.69	0.84	0.70	0.55
BAIp	0.84	0.02	0.78-0.89	0.200	21.58	0.90	0.69	0.59
BMI	0.85	0.02	0.80-0.90	<0.001	21.92	0.90	0.68	0.59
BRI	0.84	0.02	0.80-0.89	0.189	2.85	0.84	0.74	0.58
C-Index	0.73	0.04	0.65-0.80	<0.001	1.15	1.13	0.81	0.58
BF (%)	0.81	0.03	0.73-0.88	0.094	32.42	0.87	0.66	0.54
WC	0.86	0.02	0.82-0.90	1.000	72.00	1.00	0.67	0.67
WHR	0.71	0.04	0.62-0.81	<0.001	0.86	0.75	0.66	0.42
WHtR	0.85	0.02	0.80-0.90	<0.001	0.47	0.84	0.74	0.59

DeLong et al.'s non-parametric approach was used to compare the AUCs of indices with WC. Youden Index was calculated as sensitivity + specificity – 1.

ABSI, a body shape index; AVI, abdominal volume index; AUC, area under the curve; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-Index, conicity Index; BF, body fat content; MetS, metabolic syndrome; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 4. Area under the curve (AUC) in receiver-operator curves (ROC) analysis of different anthropometric indexes for discriminating between MetS components in boys.

	Abdominal obesity			Hypertriglyceridemia			Hyperglycemia			Hypertension			Low-HDL		
	AUC	95% CI	p	AUC	95% CI	p	AUC	95% CI	p	AUC	95% CI	p	AUC	95% CI	p
ABSI	0.71	0.67-0.76	<0.001	0.54	0.39-0.70	0.52	0.55	0.43-0.67	0.34	0.54	0.48-0.59	0.21	0.58	0.51-0.65	0.02
AVI	1.00	1.00-1.00	<0.001	0.49	0.36-0.62	0.84	0.52	0.42-0.63	0.70	0.77	0.73-0.81	<0.001	0.56	0.49-0.63	0.08
BAI	0.81	0.77-0.85	<0.001	0.42	0.26-0.57	0.22	0.46	0.34-0.57	0.40	0.65	0.60-0.70	<0.001	0.53	0.46-0.61	0.32
BAIp	0.91	0.88-0.94	<0.001	0.39	0.24-0.53	0.10	0.46	0.34-0.57	0.44	0.71	0.66-0.76	<0.001	0.54	0.47-0.61	0.26
BMI	0.93	0.91-0.95	<0.001	0.44	0.31-0.57	0.38	0.48	0.38-0.58	0.72	0.77	0.74-0.83	<0.001	0.54	0.47-0.61	0.27
BRI	0.95	0.93-0.96	<0.001	0.52	0.38-0.65	0.82	0.53	0.42-0.64	0.61	0.72	0.68-0.77	<0.001	0.58	0.51-0.64	0.03
C-Index	0.86	0.83-0.89	<0.001	0.55	0.41-0.69	0.45	0.56	0.44-0.67	0.29	0.63	0.58-0.69	<0.001	0.59	0.53-0.66	0.01
BF (%)	0.87	0.84-0.90	<0.001	0.52	0.40-0.64	0.80	0.54	0.44-0.63	0.47	0.71	0.66-0.76	<0.001	0.55	0.48-0.61	0.19
WC	1.00	1.00-1.00	<0.001	0.49	0.36-0.62	0.86	0.52	0.42-0.63	0.69	0.77	0.73-0.81	<0.001	0.56	0.50-0.63	0.07
WHR	0.84	0.80-0.87	<0.001	0.63	0.49-0.78	0.05	0.59	0.48-0.70	0.09	0.69	0.64-0.74	<0.001	0.59	0.52-0.66	0.01
WHtR	0.95	0.93-0.96	<0.001	0.52	0.38-0.65	0.82	0.53	0.42-0.64	0.61	0.72	0.68-0.77	<0.001	0.58	0.51-0.64	0.03

p, asymptotic significance for the ROC curve. ABSI, a body shape index; AVI, abdominal volume index; AUC, area under the curve; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-Index, conicity index; BF, body fat content; MetS, metabolic syndrome; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 5. Area under the curve (AUC) in receiver-operator curves (ROC) analysis of different anthropometric indexes for discriminating between MetS components in girls.

	Abdominal obesity			Hypertriglyceridemia			Hyperglycemia			Hypertension			Low-HDL		
	AUC	95% CI	p	AUC	95% CI	p	AUC	95% CI	p	AUC	95% CI	p	AUC	95% CI	p
ABSI	0.73	0.69-0.77	<0.001	0.43	0.32-0.53	0.35	0.53	0.43-0.62	0.58	0.50	0.45-0.55	0.925	0.48	0.42-0.55	0.63
AVI	1.00	1.00-1.00	<0.001	0.56	0.37-0.76	0.41	0.50	0.39-0.62	0.95	0.75	0.71-0.80	<0.001	0.47	0.41-0.54	0.41
BAI	0.86	0.83-0.89	<0.001	0.55	0.37-0.72	0.54	0.47	0.36-0.58	0.53	0.71	0.66-0.75	<0.001	0.46	0.40-0.53	0.24
BAIp	0.93	0.91-0.95	<0.001	0.57	0.38-0.76	0.36	0.47	0.35-0.59	0.58	0.73	0.69-0.78	<0.001	0.46	0.39-0.53	0.21
BMI	0.92	0.89-0.94	<0.001	0.57	0.38-0.77	0.35	0.47	0.35-0.58	0.53	0.79	0.74-0.83	<0.001	0.47	0.41-0.54	0.41
BRI	0.97	0.96-0.98	<0.001	0.54	0.35-0.72	0.63	0.49	0.38-0.60	0.85	0.74	0.70-0.79	<0.001	0.47	0.40-0.53	0.34
C-Index	0.88	0.85-0.91	<0.001	0.50	0.36-0.64	0.98	0.52	0.42-0.63	0.65	0.61	0.56-0.66	<0.001	0.48	0.42-0.55	0.58
BF(%)	0.87	0.84-0.90	<0.001	0.62	0.42-0.81	0.13	0.49	0.38-0.60	0.84	0.74	0.70-0.79	<0.001	0.49	0.42-0.55	0.73
WC	1.00	1.00-1.00	<0.001	0.56	0.36-0.76	0.42	0.50	0.39-0.62	0.93	0.75	0.71-0.80	<0.001	0.47	0.41-0.54	0.43
WHR	0.83	0.79-0.86	<0.001	0.51	0.37-0.66	0.85	0.52	0.42-0.63	0.66	0.67	0.62-0.72	<0.001	0.50	0.44-0.57	0.97
WHtR	0.97	0.96-0.98	<0.001	0.54	0.35-0.72	0.63	0.49	0.38-0.60	0.85	0.74	0.70-0.79	<0.001	0.47	0.40-0.54	0.34

p, asymptotic significance for the ROC curve. ABSI, a body shape index; AVI, abdominal volume index; AUC, area under the curve; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-Index, conicity index; BF, body fat content; MetS, metabolic syndrome; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Supplementary Table 1. Discriminating accuracy of the analysis for predicting MS in boys by anthropometric index.

	Detection rate	False positive rate	Positive LR	Negative LR	PPV	NPV	Effectiveness (%)
ABSI	0.6	0.1	5.0	0.4	0.00	0.91	91.0
AVI	1.0	0.0	1000.0	0.0	0.24	0.92	88.6
BAI	0.9	0.2	5.0	0.1	0.00	0.91	91.0
BAIp	1.0	0.1	7.0	0.0	0.00	0.91	91.0
BMI	0.9	0.1	15.7	0.1	0.33	0.91	90.4
BRI	1.0	0.1	17.6	0.0	0.19	0.91	88.8
C-index	0.9	0.1	12.8	0.2	1.00	0.91	91.2
Fat (%)	0.8	0.1	14.3	0.2	0.00	0.91	91.0
WC	1.0	0.0	1000.0	0.0	0.86	0.91	91.0
WHR	1.0	0.2	5.9	0.0	0.29	0.91	90.4
WHtR	1.0	0.1	13.5	0.0	0.00	0.91	90.1

ABSI, a body shape index; AVI, abdominal volume index; AUC, area under the curve; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-index, conicity index; Fat, body fat content; LR, likelihood ratio; MS, metabolic syndrome; NPV, negative predictive value; PPV positive predictive value; WC, waist circumference; WHR, waist-to-hip ratio, WHtR, waist-to-height ratio..

Supplementary table 2. Discriminating accuracy of the analysis for predicting MS in girls by anthropometric index.

	Detection rate	False positive rate	Positive LR	Negative LR	PPV	NPV	Effectiveness (%)
ABSI	0.9	0.5	1.75	0.26	0.00	0.93	93.9
AVI	1.0	0.0	>1000.00	0.00	0.22	0.95	92.0
BAI	0.9	0.2	5.19	0.18	0.40	0.94	93.7
BAIp	0.9	0.2	5.96	0.10	0.25	0.94	93.1
BMI	0.9	0.1	8.40	0.13	0.37	0.95	93.0
BRI	1.0	0.1	9.36	0.01	0.00	0.95	92.0
C-Index	0.9	0.2	4.25	0.13	0.00	0.94	93.9
Fat (%)	0.9	0.1	6.82	0.17	0.00	0.94	93.9
WC	1.0	0.0	>1000.00	0.00	0.33	0.95	93.1
WHR	0.9	0.2	4.84	0.19	0.00	0.94	93.9
WHtR	1.0	0.1	8.62	0.02	0.00	0.95	93.0

ABSI, a body shape index; AVI, abdominal volume index; AUC, area under the curve; BAI, body adiposity index; BAIp, pediatric body adiposity index; BMI, body mass index; BRI, body roundness index; C-index, conicity index; Fat, body fat content; LR, likelihood ratio; MS, metabolic syndrome; NPV, negative predictive value; PPV positive predictive value; WC, waist circumference; WHR, waist-to-hip ratio, WHtR, waist-to-height ratio.