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Original article

Predictive Ability of Seven Anthropometric Indices for Cardiovascular Risk Markers and Metabolic Syndrome in Adolescents

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A B S T R A C T

Purpose: The aim of the study was to evaluate the reliability of 7 anthropometric indices in predicting cardiovascular risk markers (CRMs) and metabolic syndrome (MetS) in Brazilian adolescents.
Methods: A cross-sectional study conducted with 1,069 participants of the Cardiovascular Risk in Adolescents Study aged 12–17 years. Receiver operating characteristics curves were plotted, and area under curve (AUC) was calculated for body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHR), conicity index (CoI), body shape index (BSI), adjusted BSI for adolescents (adjusted BSI), and body roundness index (BRI).
Results: In girls, reliability of BMI, WC, WHR, and BRI was sufficient (≥.6 AUC <.7) only to predict high blood pressure. Among boys, reliability of BMI, WC, WHR, BRI, and adjusted BSI ranged from good to sufficient (≥6 AUC <.8) to predict insulin resistance and high blood pressure, but poor to sufficient (≥.5 AUC <.7) for high total cholesterol, triglycerides, and low-density lipoprotein. For both sexes, CoI and BSI presented AUC ≤.5 for all CRM. A majority of the anthropometric indices showed AUC ≥.9 for MetS.
Conclusion: Reliability of CoI, BSI, adjusted BSI, and BRI is not superior to BMI, WC, and WHR in predicting CRM and MetS. All the anthropometric indices had excellent predictive capacity for MetS, but limited accuracy for CRM. Among the evaluated indices, we recommend the use of cutoff point WHR ≥.55 to screening MetS in girls and boys because of its easy to measure and interpretation.

IMPLICATIONS AND CONTRIBUTION

This study presented a broad approach to reliability of 7 anthropometric indices to predict cardiovascular risk markers and metabolic syndrome. Findings demonstrate that anthropometry is an excellent tool for the screening of metabolic syndrome; however, its reliability to predict individual cardiovascular risk markers is limited.

The identification of cardiovascular risk factors in children and adolescents is one of the strategies for the reduction of cardiovascular morbidity and mortality, according to the World Health Organization [1]. Accordingly, tools for the screening of CRMs in early life have been widely studied.

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Global and central obesity in adolescents are predictive of type II diabetes mellitus, hypertension, dyslipidemia, and metabolic syndrome (MetS) [2]. Thus, anthropometric indices have been proposed to predict the amount and location of body fat to track metabolic disorders [3]. The advantages of anthropometric parameters are related to the ease of obtaining measurements and are less invasive and inexpensive compared with biochemical or imaging tests. These features offer a practical option in a clinical setting and population studies [3,4].

Results from longitudinal studies, ranging from childhood to adulthood, identified that anthropometric measurements in childhood are predictors of cardiovascular risk in adulthood [5,6]. Among the proposed anthropometric indices, body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHR) are the most studied. Meta-analysis gathered cross-sectional studies that evaluated the screening power of individual cardiovascular risk factors and MetS in childhood and adolescence. The mean area under curve (AUC) values for each index were greater than .6 for most outcomes; therefore, they are useful in screening of diabetes, dyslipidemia, hypertension, and MetS in this age [7].

However, literature presents conflicting findings on which index best predicts cardiovascular risk in children and adolescents. Some authors claim that BMI, WC, and WHR have the same discriminatory power [8–10]; according to others, the reliability of anthropometric indices depends on CRM, sex, phase of adolescence, and nutritional status [11,12]. The suggestion that there may be an index with better predictive capacity than other is because BMI is associated with global obesity, whereas WHR and WC are associated with central body fat concentration [6]. Moreover, in adolescence, shape and composition body are constantly changing and vary according to sex and age, which may influence the reliability of the indices [13].

In view of these divergences and seeking to produce alternative anthropometric indices with greater sensitivity, other proposals were developed as conicity index (CoI) [14], body shape index (BSI) [15], and body roundness index (BRI) [16]. These indices were produced based on adulthood and, generally, present satisfactory predictive capacity in this population group [17,18].

CoI was able to predict MetS [19] and insulin resistance (IR) [20] in a cross-sectional studies in adolescents. Furthermore, in sample design studies similar, BSI was negatively associated with blood pressure (BP) in Portuguese adolescents [21], whereas this association was positive among adults [18]. As this result was unexpected, BSI formula exponents were adjusted based on the assumption that adolescent body shape is different from adult [22]. After exponential correction, adjusted BSI for adolescents showed sufficient predictive capacity for glycated hemoglobin [22], hypertension, and high fasting glycemia (FG) [23]. Despite the promising results, it is not clear whether these indices have superior reliability than BMI, WC, and WHR.

BRI was proposed in 2014 [16]. In adults and the elderly, this index presented satisfactory reliability for the prediction of diabetes mellitus, hypertension, dyslipidemia, hyperuricemia, and MetS [24,25]. However, to date, no studies have been conducted with adolescents.

Given the arguments presented, our hypotheses are (1) alternative indices do not have greater predictive capacity than BMI, WC, and WHR and (2) among indices evaluated, there is one with greater reliability for screening individual markers of cardiovascular risk and MetS. Thus, this study evaluated the reliability of 7 anthropometric indices to predict CRMs and MetS in adolescents according to sex.

Methods

Study population

This study used a subsample of the Cardiovascular Risk in Adolescents Study (ERICA), collected in the city of Palmas, capital of Tocantins, Brazil. ERICA is a cross-sectional, population-based study conducted with 74,589 adolescents aged 12–17 years, both sexes, public and private school students in urban and rural areas.

The study population was stratified into 32 geographic strata and clustered in 3 stages: schools, combination of shifts and grade, and class. Sample size was estimated considering the prevalence of MetS at the national and local levels. For the city of Palmas, the estimated sample size was 1,200 students, 60 classes, and 20 schools. Sample design details were published elsewhere [26]. Our analysis is limited from city of Palmas, located in the northern region of Brazil, because among the country capitals, this is one with the lowest prevalence of obesity and hypertension in adolescence [27].

The inclusion criteria were adolescents aged between 12 and 17 years whose parents and/or guardians signed informed consent form and who also agreed to participate in the study. The exclusion criteria were pregnancy and physical disabilities, which limit the collection of anthropometric measurements.

Data collection

Anthropometric and sociodemographic data, BP, and blood samples were collected in the schools. The information was recorded in a Personal Digital Assistant (PDA). The data collection protocol was previously described in a specific publication [26].

The research team consisted of a regional leader, 3 local supervisors, and 5 evaluators. The study's Steering Committee developed an operation manual. Regional team leader was trained by this committee and replicated the training with field workers. Videos were produced specially to assist in the training of anthropometric and BP measurements. Data entry into the PDA was regularly checked by performing logical checks to identify outliers or digit preference in measurements. Extreme values were standardized in a pilot study. The evaluators were retrained, and equipment was checked or replaced when a problem was detected [26].

Sociodemographic variables

Sociodemographic variables, such as sex, age, race/ethnicity, and characteristics, of household head were obtained from a questionnaire answered by the adolescents. Socioeconomic status was classified as class A, B, C, and D, based on the Brazilian Economic Classification Criterion developed by the Brazilian Association of Research Companies, being Class A the highest socioeconomic status and D the lowest [28].

Anthropometric measures and indices

Weight, height, and WC measurements were taken over light clothing, and the individuals were barefooted. Height was measured in duplicate using an Alturexata portable stadiometer with a 2.13 m extension and 1 mm accuracy. The participants were weighed on a Líder digital scale with 200 kg capacity and 50 g precision. WC was measured at the midpoint between the upper border of the iliac crest and the lower margin of the rib using a 1.5 m Sanny fiberglass anthropometric tape with precision of 1 mm.

To classify the nutritional status of adolescents, the World Health Organization reference curves were adopted using the BMI for age according to gender [29]. The cutoff points adopted were Z-score <-2 (underweight), Z-score ≥ -2 and ≤ 1 (normal weight), Z-score >1 (overweight) and ≤ 2, and Z-score >2 (obesity).

From weight, height, and WC measurements were calculated the BMI as weight (kilogram)/(height (meter))^2, WHR as waist (centimeter)/height (centimeter), CoI as $\frac{\mathrm{WC(m)}}{0.109 \times \sqrt{\frac{\mathrm{weight(kg)}}{\mathrm{height(m)}}}}$, BRI as $364.2 - 365.5 \times \sqrt{1 - \left[\frac{(\mathrm{WC(m)} \div (2\pi))^2}{(0.5 \times \mathrm{height(m)})^2}\right]}$, BSI as $\frac{\mathrm{WC(m)}}{\mathrm{BMI}^{2/3} \times \mathrm{height(m)}^{1/2}}$, and adjusted BSI for adolescents (adjusted BSI) as $\frac{\mathrm{WC(m)}}{BMI^{0.45} \times \mathrm{height(m)}^{0.55}}$.

Blood pressure

BP measurements were obtained according to the standards of the ERICA protocol [26]. High BP levels were defined as systolic BP (SBP) and/or diastolic BP (DBP) above 90th percentile according to age, sex, and percentile of height or SBP/DBP $\geq$120/80 mm Hg [30].

Biochemical measurements

Blood samples were taken from only morning shift students because of the 12-hour fasting requirement. The samples were analyzed for levels of glucose, insulin, total cholesterol (TC), high-density lipoprotein (HDL), low-density lipoprotein (LDL), and triglycerides (TG).

High lipemic levels were TC $\geq$170 mg/dL, LDL $\geq$110 mg/dL, HDL $<$45 mg/dL, TG $\geq$100 mg/dL, and FG $\geq$100 mg/dL [31]. IR was evaluated by Homeostatic Model Assessment-Insulin Resistance and classified according to sex-specific 90th percentile of the population.

The diagnosis of MetS was based on the International Diabetes Federation criteria for children and adolescents [32].

Statistical analyses

The general characteristics of the population were analyzed according to sex. Categorical variables were expressed as percentage and 95% confidence interval (95% CI) and were compared with the chi-square test. Numerical variables were tested for normality by histogram and Kolmogorov–Smirnov test. Variables with normal distribution were compared by the Student *t*-test, and those that did not follow a normal distribution were compared by the Mann–Whitney test.

The receiver operating characteristics (ROC) curves were generated to estimate the predictive capacity of the anthropometric indices and cutoff points. Areas under ROC curve (AUC) and 95% CIs were calculated. The capacity of an anthropometric index to predict CRMs was identified by rejecting the null hypothesis (AUC = .05). The accuracy of the anthropometric index was given by the classification of AUC values: between $\geq$.5 and $<$.6 poor, $\geq$.6 and $<$.7 sufficient, $\geq$.7 and $<$.8 good, $\geq$.8 and $<$.9 very good, and $\geq$.9 excellent [33]. The AUC were compared in pairs by the nonparametric DeLong test to identify the predictive superiority of all the indices in relation to BMI, WC, and WHR.

The cutoff point for the anthropometric indices was the highest Youden Index; this index is given by the following formula: sensitivity + specificity − 1 [34]. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated from the estimated cutoffs.

All statistical analysis was performed considering the complex sampling design of the study. The descriptive analyses were done using the survey extension of Stata version 13.0 (StataCorp, College Station, TX). The ROC curves were generated in the survey and pRoc libraries of R version 3.5.1. A significance level of $\alpha = .5$ was considered for all the analyses.

Ethics

ERICA was approved by the Human Research Ethics Committee of the Federal University of Rio de Janeiro in January 2009 (protocol no. 01/2009) and President António Carlos Institute of Tocantins in February 2014 (protocol no.534.749).

Results

Of the 1,200 adolescents, 1,069 adolescents (89.1%) completed the phases of the study: socioeconomic questionnaire and anthropometric and BP measurements. Among the 726 morning shift students, 548 (75.5%) underwent biochemical tests. From the assessment of the nutritional status of adolescents, we identified 3.71% are underweight, 79.19% are normal weight, 11.95% are overweight, and 5.15% are obese.

According to the sociodemographic characteristics of the general population, a greater proportion was nonwhite adolescents, of class B status and public school students. In relation to sex, we found a higher proportion of boys in class A (p = .003) and girls in class C + D (p = .031). Regarding the anthropometric data, the boys presented higher weight, height, WC, CoI, BSI, and adjusted BSI than the girls (Table 1).

Regarding clinical and biochemical data, higher SBP and DBP were observed in boys, whereas higher TC, insulin, and Homeostatic Model Assessment-Insulin Resistance were found in girls. The most frequent CRM were low HDL and high TC, affecting 58.5% and 41.9% of adolescents, respectively. The prevalence of high LDL, TG, BP, and IR was between 10% and 25%. High FG and MetS affected 5.2% and 2.5% of the population, respectively. The proportion of boys with high BP was higher compared with girls (26.5% vs. 7.7%; $p < .001$; Table 2).

The AUC constructed for girls are presented in Table 3. BMI, WC, WHR, and BRI had sufficient predictive capacity (AUC $\geq$.6 and $<$.7) for high BP and did not differ from each other. No anthropometric index was able to predict high TC, LDL, TG, FG, low HDL, and IR. All the indices achieved excellent predictive capacity for MetS (AUC $\geq$.9) and did not differ from each other.

Table 4 presents AUC for boys. From curves of BMI (AUC = .739) and WC (AUC = .723) presented good predictive capacity for high BP, whereas WHR, BRI, and adjusted BSI showed sufficient reliability ($\geq$.6 AUC $<$.7). BMI and WC presented superior reliability to predict high BP over other indices. The predictive

Table 1
Sociodemographic and anthropometric characteristics of adolescents according to sex

Variable	Overall (n = 1,069)	Female (n = 570)	Male (n = 499)	*p* value
Sociodemographic profile				
Skin color, % (95% CI)				
Nonwhite	74.1 (67.1–79.9)	75.9 (68.6–81.9)	72.1 (64.3–78.7)	.145[a]
White	25.9 (20.5–32.8)	24.1 (18.0–31.3)	27.9 (21.2–35.6)	
Socioeconomic level, % (95% CI)				
Level A	17.6 (8.9–31.6)	13.8 (6.2–27.5)	21.5 (11.5–36.6)	.006[a,b]
Level B	49.0 (44.1–53.8)	48.9 (43.7–53.0)	49.1 (41.8–56.3)	
Level C + D	33.4 (25.5–42.4)	37.3 (28.3–47.3)	29.4 (21.3–38.9)	
School funding, % (95% CI)				
Public	89.1 (65.8–97.2)	88.6 (64.5–97.1)	89.5 (66.7–97.3)	.569[a]
Private	10.9 (2.8–3.4)	11.4 (2.9–35.4)	10.5 (2.6–33.2)	
Anthropometry				
Weight (kg), mean (SE)	54.4 (.7)	52.0 (.6)	56.9 (1.0)	<.001[c]
Height (m), mean (SE)	163.1 (.5)	159.5 (.4)	166.9 (.7)	<.001[c]
BMI (kg/m^2), mean (SE)	20.3 (.2)	20.4 (.2)	20.2 (.3)	.454[c]
WC (cm), mean (SE)	69.5 (.6)	67.9 (.6)	71.1 (.7)	<.001[c]
WHR, median (IQI)	.41 (.39–.45)	.41 (.39–.45)	.41 (.39–.44)	.409[d]
CoI, median (IQI)	1.10 (1.07–1.14)	1.09 (1.05–1.13)	1.12 (1.08–1.15)	<.001[d]
BSI, mean (SE)	.12 (.00)	.11 (.00)	.12 (.00)	<.001[c]
Adjusted BSI, mean (SE)	.23 (.00)	.22 (.00)	.24 (.00)	<.001[c]
BRI, mean (SE)	2.12 (.05)	2.12 (.06)	2.13 (.06)	.409[d]

BMI = body mass index; BRI = body roundness index; BSI = body shape index; CI = confidence interval; CoI = conicity index; IQI = interquartile interval; SE = standard error; WC = waist circumference; WHR = waist-to-height ratio.
[a] Chi-square test.
[b] Comparison between genders: Level A $p = .003$; Level B $p = .936$; Level C $p = .031$.
[c] *T* test.
[d] Mann–Whitney test.

capacity of BMI, WC, WHR, and BRI ranged from poor to sufficient ($\geq$.5 AUC <.7) for high TC, LDL, and TG. For IR, the BMI and CoI showed sufficient reliability ($\geq$.6 AUC <.7), WC, WHR, and BRI showed good reliability ($\geq$.7 AUC <.8). No anthropometric index was able to predict altered FG. All the indices presented very good to excellent predictive capacity for MetS and did not differ from each other.

For both sexes, all AUC for adjusted BSI were higher than unadjusted BSI (data not shown). CoI and BSI presented AUC $\leq$.5 for all CRM. All AUC values for WHR and BRI were equal as well as their 95% CIs.

The calculated cutoff points for MetS are shown in Table 5. All the anthropometric indices presented 100% sensitivity for the identification of MetS, except for BSI. For both sexes, WHR and BRI presented the highest sensitivity, specificity, PPV, NPV, and Youden Index. A WHR >.55 in girls and boys, and a BRI >4.38 in girls and >4.48 in boys were able to discriminate MetS in adolescents.

Table 2
Distribution of biochemical, clinical, and cardiovascular risk factors variables in adolescents according to sex

Biochemical and clinical measurements	Overall (n = 548)	Female (n = 310)	Male (n = 238)	*p* value
TC (mg/dL), mean (SE)	79.5 (1.5)	81.6 (1.9)	77.5 (3.3)	**.032**[a]
LDL (mg/dL), mean (SE)	83.9 (1.1)	85.4 (1.4)	82.4 (1.4)	.131[a]
HDL (mg/dL), mean (SE)	43.3 (.6)	44.1 (.7)	42.5 (.7)	.052[a]
TG (mg/dL), median (IQI)	74.0 (57.0–94.0)	74.0 (58.0–96.0)	73.0 (54.0–93.0)	.376[b]
FG, mg/dL	87.4 (.9)	87.2 (.8)	87.6 (2.0)	.864[a]
Insulin (mg/dL), median (IQI)	6.4 (4.0–9.6)	7.1 (4.6–10.2)	5.6 (3.2–8.3)	**<.001**[b]
HOMA-IR, median (IQI)	1.4 (.9–2.1)	1.5 (1.0–2.2)	1.3 (.7–1.9)	**.003**[b]
SBP (mm Hg), mean (SE)[c]	108.3 (.7)	104.7 (.9)	111.9 (1.00)	**<.001**[a]
DBP (mm Hg), mean (SE)[c]	64.4 (.4)	63.5 (.6)	65.2(.6)	**.018**[a]
High TC, % (95% CI)	41.9 (35.3–48.8)	44.8 (39.2–50.5)	38.9 (29.4–49.3)	.188[d]
High LDL, % (95% CI)	25.0 (17.9–33.7)	26.2 (20.3–33.1)	23.7 (14.2–36.9)	.598[d]
Low HDL, % (95% CI)	58.5 (49.8–66.6)	55.5 (37.4–51.7)	61.5 (49.8–72.0)	.153[d]
High TG, % (95% CI)	20.7 (17.2–24.6)	22.5 (18.5–27.2)	18.1 (12.6–27.1)	.414[d]
High FG, % (95% CI)	5.2 (2.8–9.4)	4.1 (2.1–7.7)	6.4 (2.8–13.9)	.286[d]
High BP, % (95% CI)[c]	16.9 (13.8–20.6)	7.7 (5.2–11.3)	26.5 (21.6–32.1)	**<.001**[d]
IR, % (95% CI)	9.9 (7.5–13.1)	11.2 (7.3–16.9)	8.6 (5.3–13.5)	.407[d]
MetS, % (95% CI)	2.5 (1.2–5.2)	1.4 (.4–4.0)	3.7 (1.7–8.0)	.053[d]

Bold values represent $p \leq .05$.
BP = blood pressure; CI = confidence interval; DBP = diastolic blood pressure; FG = fasting glycemia; HDL = high-density lipoprotein; HOMA-IR = Homeostatic Model Assessment-Insulin Resistance; IQI = interquartile interval; IR = insulin resistance; LDL = low-density lipoprotein; MetS = metabolic syndrome; SBP = systolic blood pressure; SE = standard error; TC = total cholesterol; TG: triglycerides.
[a] *T* test.
[b] Mann–Whitney test.
[c] n = 1,069.
[d] Chi-square test.

Table 3
Areas under receiver operating characteristics curve of the predictive anthropometric indicators of cardiovascular risk markers and metabolic syndrome in girls

	BP, AUC (95% CI)	TC, AUC (95% CI)	LDL, AUC (95% CI)	HDL, AUC (95% CI)	TG, AUC (95% CI)	FG, AUC (95% CI)	IR, AUC (95% CI)	MetS, AUC (95% CI)
BMI	**.698**[d] (.611–.785)	.564 (.498–.629)	.581 (.495–.662)	.535 (.470–.599)	.518 (.430–.605)	.508 (.316–.700)	.546 (.441–.650)	**.985**[e] (.970–1.0)
WC	**.673**[d] (.588–.759)	.543 (.475–.608)	.567 (.482–.650)	.566 (.501–.629)	.527 (.439–.613)	.466 (.298–.633)	.525 (.412–.636)	**.979**[e] (.957–1.0)
WHR	**.686**[d] (.605–.766)	.560 (.491–.626)	.570 (.485–.654)	.555 (.490–.618)	.554 (.467–.640)	.541 (.357–.724)	.476 (.364–.588)	**.998**[e] (.994–1.0)
BRI	**.686**[d] (.605–.766)	.560 (.491–.626)	.570 (.485–.654)	.555 (.490–.618)	.554 (.467–.640)	.541 (.357–.724)	.476 (.364–.588)	**.998**[e] (.994–1.0)
CoI	.578[a,b,c] (.488–.667)	.505 (.438–.570)	.531 (.448–.614)	.570 (.505–.633)	.542 (.460–623)	.596 (.412–.778)	.497 (.387–.606)	**.970**[d] (.936–1.0)
BSI	.471[a,b,c] (.376–.566)	.559 (.493–.624)	.533 (.453–.613)	.556 (.492–.620)	.530 (.446–.612)	.557 (.353–.760)	.537 (.433–.641)	**.909**[d] (.805–1.0)
Adjusted BSI	.565[a,b,c] (.470–.660)	.524 (.457–.590)	.484 (.402–.565)	.578 (.513–.641)	.522 (.439–.605)	.547 (.338–.755)	.468 (.356–.579)	**.983**[e] (.948–1.0)

Bold values represent $p \leq .05$.
AUC = areas under curve; BMI = body mass index; BP = blood pressure; BSI = body shape index; BRI = body roundness index; CI = confidence interval; CoI = conicity index; FG = fasting glycemia; HDL = high-density lipoprotein; IR = insulin resistance; LDL = low-density lipoprotein; MetS = metabolic syndrome; TC = total cholesterol; TG = triglycerides; WC = waist circumference; WHR = waist-to-height ratio.
Comparison between curves: [a] compared with BMI. [b] compared with WC. [c] compared with WHRs; $p < .05$.
[d] $p < .05$.
[e] $p < .001$ (null hypothesis AUC = .5).

Discussion

This study provides information about the capacity of 7 anthropometric indices to predict CRM and MetS in adolescents aged 12–17 years, according to sex. We observed limited accuracy of the anthropometric indices in predicting individual cardiovascular risk markers, especially in girls. For MetS, all the indices showed very good to excellent reliability. In both boys and girls, CoI, BSI, adjusted BSI, and BRI presented equal or lower reliability in relation to BMI, WC, and WHR. Thus, conventional indices are still the best choice among indices for screening cardiovascular risk in adolescence.

For most individual cardiovascular risk markers, AUC values were $\geq .5$ and $< .7$; thus, the predictive capacity of the anthropometric indices was classified as poor to sufficient, presenting limited reliability. In previous cross-sectional studies with adolescents, AUC for dyslipidemia, diabetes mellitus, and arterial hypertension were also lower than .7 [8,9]. On the other hand, reliability of anthropometric indices for tracking individual cardiovascular risk markers from studies conducted with the adult and elderly population is greater, ranging from sufficient to good [17,18,35]. This divergence of findings between different life stages can be explained by the fact of cardiovascular diseases to be a chronic condition and may take time to establish so that body shape more reliably reflects cardiometabolic condition. Thus, both body shape and cardiovascular risk markers may not be fully established in adolescence, which interfere on reliability of anthropometric indices.

Unlike individual cardiovascular risk markers, all the anthropometric indices presented very good to excellent predictive capacity for MetS, and there is not an index with superior predictive capacity than other. Similar findings are observed in other studies in adolescents [10,11]. This is because of the fact that individuals with greater body fat and abdominal circumference are more likely to present simultaneous metabolic changes [36]. This condition increases test accuracy, yielding AUC that reflect high predictive capacity.

From the ideal cutoff points calculated by Youden index to screening MetS, we found similar measures of performance for all indices. However, we recommend the use of WHR $\geq .55$ in both sexes because it is easy to measure and not requiring tables, growth curves, age- and sex-specific cutoff points compared with BMI and WC [7]. In addition, biological mechanisms responsible for the association between abdominal fat concentration and MetS support this recommendation. Higher waist circumference is associated with higher amount of ectopic fat. Lipolysis of this tissue releases free fatty acids that can induce hepatic IR, provide substrate for lipoproteins synthesis and lipid storage in hepatocytes, and induce production of inflammatory adipokines, angiotensinogen, and cortisol [37]. Therefore, WHR is not only an excellent tool for screening of MetS but also a potent risk factor for this metabolic condition.

Other authors too propose the use of WHR for the prediction of MetS; however, variations in cutoff points have been observed [19,38]. Cross-sectional studies with Brazilian adolescents found WHR cutoff points for screening for MetS slightly lower than those presented in our study. Ribeiro-Silva et al. identified WHR $>.447$ for girls and $>.448$ for boys with a sensitivity of 76%–78%, respectively [38], and Oliveira et al. found WHR $>.46$ (aged 12–15 years) and $>.48$ (aged 16–20 years) with 60% sensitivity and 70% specificity [19]. In these studies, the cutoff points were estimated based on the balance between sensitivity and

Table 4
Areas under receiver operating characteristics curve of the predictive anthropometric indicators of cardiovascular risk markers and metabolic syndrome in boys

	BP, AUC (95% CI)	TC, AUC (95% CI)	LDL, AUC (95% CI)	HDL, AUC (95% CI)	TG, AUC (95% CI)	FG, AUC (95% CI)	IR, AUC (95% CI)	MetS, AUC (95% CI)
BMI	**.739**[d,c] (.690–.781)	**.603**[d] (.526–.679)	**.661**[d] (.559–.761)	**.642**[d] (.567–.716)	**.651**[d] (.564–.738)	.559 (.421–.696)	**.687**[d] (.554–.820)	**.972**[e] (.946–.996)
WC	**.723**[d,c] (.679–.773)	**.596**[d] (.518–.673)	**.659**[d] (.559–.758)	**.650**[d] (.576–.724)	**.640**[d] (.551–.729)	.537 (.386–.686)	**.681**[d] (.531–.831)	**.984**[e] (.968–1.0)
WHR	**.674**[d,a,b] (.620–.727)	**.615**[d] (.538–.691)	**.633**[d] (.529–.736)	**.591**[d] (.516–.665)	**.650**[d] (.562–.738)	.575 (.431–.719)	**.726**[d] (.586–.865)	**.985**[e] (.968–1.0)
BRI	**.674**[d,a,b] (.620–.727)	**.615**[d] (.538–.691)	**.633**[d] (.529–.736)	**.591**[d] (.516–.665)	**.650**[d] (.562–.738)	.575 (.431–.719)	**.726**[d] (.586–.865)	**.985**[e] (.968–1.0)
CoI	.537[a,b,c] (.478–.595)	.559 (.480–.638)	.561 (.448–.674)	.538 (.462–.612)	.560 (.464–.654)	.519 (.363–.675)	**.689**[d] (.548–.829)	**.967**[e] (.926–1.0)
BSI	.542[a,b,c] (.485–.599)	.505 (.425–.580)	.550 (.448–.651)	.575 (.499–.650)	.517 (.423–.610)	.536 (.405–.666)	.514 (.364–.663)	**.876**[e] (.753–.997)
Adjusted BSI	**.642**[d,a,b] (.586–.697)	.543 (.463–.621)	**.602**[d] (.504–.710)	**.620**[d] (.544–.695)	.560 (.468–.652)	.506 (.361–.650)	.596 (.449–.743)	**.992**[e] (.980–1.0)

Bold values represent $p \leq .05$.
AUC = areas under curve; BMI = body mass index; BP = blood pressure; BSI = body shape index; BRI = body roundness index; CI = confidence interval; CoI = conicity index; FG = fasting glycemia; HDL = high-density lipoprotein; IR = insulin resistance; LDL = low-density lipoprotein; MetS = metabolic syndrome; TC = total cholesterol; TG = triglycerides; WC = waist circumference; WHR = waist-to-height ratio.
Comparison between curves: [a] compared with BMI. [b] compared with WC. [c] compared with WHRs; $p < .05$.
[d] $p < .05$.
[e] $p < .001$ (null hypothesis AUC = .5).

specificity, while we used the Youden Index. Youden Index maximizes correct classification rates and minimizes incorrect ones; thus, the cutoff point produced by this method generates a low frequency of false positives and false negatives [39]. These factors may explain the higher cutoff point presented in our study.

We present further findings on the predictive capacity of BRI in adolescents because of the lack of previous studies. In adults, BRI was able to predict diabetes, uricemia, hypertension, dyslipidemia, and MetS and exhibited better reliability than BMI and BSI for the prediction of prediabetes [24,25]. In our results, BRI presented a sufficient predictive capacity to detect almost all cardiovascular risk markers among boys, with an emphasis on IR in boys. In girls, it was able to predict BP and MetS. However, AUC values calculated for BRI were identical to those obtained for the WHR, equal to studies in adults [24,25].

In this way, we believe that BRI does not provide additional information in relation to WHR. In addition, because of the complex calculation of BRI, an online calculator is made available. However, in large-scale screening or in situations where health professionals require real-time information, indices that can be calculated with a handheld calculator are preferred, as in the case of BMI and WHR.

None of the anthropometric indices were able to predict altered FG. Previous studies have found AUC very close to .5 or lower [9,40]. Excess weight or increase in body size may not be the most important factor for the screening of fasting glucose in adolescents, so other factors such as lifestyle and genetics could play a role in the modulation of this outcome [40].

Some limitations of the study include the fact that 25.5% of the adolescents did not participate in the blood tests. Because of this, the data were not analyzed by different phases of adolescence. Studies with adolescents may present a higher nonresponse rate because parents and/or guardians must sign an informed consent form for the participation of their children as well as the adolescent. To reduce the impact of this limitation, the data were weighted, considering the nonresponse rate [26]. Because it is a predominantly healthy population, in which occurrence of outcomes is relatively low compared with adult population, reliability of anthropometric indices may have been affected. Furthermore, analyses were not controlled by potential confounding factors such as diet, physical activity, smoking, and alcohol consumption.

The strengths of this study are related to its external validity because the sample was randomly selected from a previously defined reference population, minimizing selection biases. However, we emphasize that the external validity of these results is restricted to populations with a low prevalence of obesity and hypertension, around 5% and 7%, respectively. This is a population-based study, composed of a representative sample of the city of Palmas that had not been studied yet. We emphasize that all data used are objective and collected by trained researchers in a large sample. In addition, the data entered in the PDA by researchers was regularly checked to identify outliers and/or preference in entering specific measures, reducing the impact of typing errors.

In conclusion, anthropometric indices, such as CoI, BSI, adjusted BSI, and BRI, do not present superior reliability than BMI, WC, and WHR for the screening of CRM and MetS. The use of anthropometric indices for the prediction of CRM is limited, thus should be used with caution. This study supports the use of the WHR for the screening of MetS in adolescents, and the cutoff point ≥.55 can be used for both sexes. Although there is no

Table 5
Optimal cutoff values and measures of performance for metabolic syndrome screening in adolescents according to sex

Metabolic syndrome	Cutoff values	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Youden Index
Girls						
BMI	27.1	100.0	97.0	35.7	100.0	.97
WC	80.4	100.0	94.6	23.8	100.0	.94
WHR	.55	100.0	99.3	71.4	100.0	.99
BRI	4.38	100.0	99.3	71.4	100.0	.99
CoI	1.19	100.0	91.6	16.6	100.0	.91
BSI	.13	80.0	94.3	19.04	99.6	.74
Adjusted BSI	.25	100.0	91.3	16.1	100.0	.91
Boys						
BMI	26.3	100.0	93.8	30.0	100	.93
WC	91.2	100.0	96.0	42.8	100	.96
WHR	.55	100.0	96.9	46.1	100	.96
BRI	4.48	100.0	96.9	46.1	100	.96
CoI	1.19	100.0	87.3	17.1	100	.87
BSI	.13	83.3	82.5	11.1	99.4	.65
Adjusted BSI	.27	100.0	96.9	46.1	100.0	.96

BMI = body mass index; BSI = body shape index; BRI = body roundness index; CoI = conicity index; NPV = negative predictive value; PPV = positive predictive value; WC = waist circumference; WHR = waist-to-height ratio.

superiority in reliability among the 7 anthropometric indices for MetS and there is a similar number of false positive and negative values between them, the WHR uses easily obtainable measures (waist and height) and easy interpretation of results.

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References

[1] World Health Organization. Global action plan for the prevention and control of noncommunicable diseases 2013-2020. World Heal Organ; 2013. p. 102.
[2] Blüher S, Molz E, Wiegand S, et al. Body mass index, waist circumference, and waist-to-height ratio as predictors of cardiometabolic risk in childhood obesity depending on pubertal development. J Clin Endocrinol Metab 2013; 98:3384–93.
[3] Janssen I, Heymsfield SB, Allison DB, et al. Body mass index and waist circumference independently contribute to the prediction of non-abdominal, abdominal subcutaneous, and visceral fat. Am J Clin Nutr 2002; 75:683–8.
[4] Vasques A, Priore S, Rosado L. Utilização de medidas antropométricas para a avaliação do acúmulo de gordura visceral the use of anthropometric measures to assess visceral fat accumulation. Rev Nutr 2010;23:107–18.
[5] Wu F, Ho V, Fraser BJ, et al. Predictive utility of childhood anthropometric measures on adult glucose homeostasis measures: A 20-year cohort study. Int J Obes 2018;42:1762–70.
[6] Magnussen CG, Koskinen J, Chen W, et al. Pediatric metabolic syndrome predicts adulthood metabolic syndrome, subclinical atherosclerosis, and type 2 diabetes mellitus – but is no better than body mass index alone: The Bogalusa Heart Study and the Cardiovascular Risk in Young Finns Study. Circulation 2012;122:1604–11.
[7] Lo K, Wong M, Khalechelvam P, et al. Waist-to-height ratio, body mass index and waist circumference for screening paediatric cardio-metabolic risk factors: A meta-analysis. Obes Rev 2016;17:1258–75.
[8] 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:E256.
[9] Bauer KW, Marcus MD, El Ghormli L, et al. Cardio-metabolic risk screening among adolescents: Understanding the utility of body mass index, waist circumference and waist to height ratio. Pediatr Obes 2015; 10:329–37.
[10] Jung C, Fischer N, Fritzenwanger M, et al. Anthropometric indices as predictors of the metabolic syndrome and its components in adolescents. Pediatr Int 2010;52:402–9.
[11] Pereira PF, Faria FR, Faria ER, et al. Revista Paulista Anthropometric indices to identify metabolic syndrome and hypertriglyceridemic waist phenotype : A comparison between the three stages of adolescence 2015;33: 194–203.
[12] 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.
[13] Chipkevitch E. Puberdade & adolescência: Aspectos biológicos, clínicos e psicossociais. São Paulo: Rocca; 1995.
[14] Valdez R. A simple model-based index of abdominal adiposity. J Clin Epidemiol 1991;44:955–6.
[15] Krakauer NY, Krakauer JC. A new body shape index predicts mortality hazard independently of body mass index. PLoS One 2012;7.
[16] Thomas DM, Bredlau C, Bosy-westphal A, et al. Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model. Obesity 2014;21:2264–71.
[17] Motamed N, Perumal D, Zamani F, et al. Conicity index and waist-to-hip ratio are superior obesity indices in predicting 10-year cardiovascular risk among men and women. Clin Cardiol 2015;38:527–34.
[18] Chang Y, Guo X, Chen Y, et al. A body shape index and body roundness index: Two new body indices to identify diabetes mellitus among rural populations in northeast China. BMC Public Health 2015;15:794.
[19] Oliveira RG, Guedes DP. Performance of anthropometric indicators as predictors of metabolic syndrome in Brazilian adolescents. BMC Pediatr 2018;18:1–9.
[20] Carneiro IBP, Sampaio HA de C, Carioca AAF, et al. Antigos e novos indicadores antropométricos como preditores de resistência à insulina em adolescentes. Arq Bras Endocrinol Metabol 2014;58:838–43.
[21] Duncan MJ, Mota J, Vale S, et al. Associations between body mass index, waist circumference and body shape index with resting blood pressure in Portuguese adolescents. Ann Hum Biol 2013;40:163–7.
[22] Xu Y, Yan W, Cheung YB. Body shape indices and cardiometabolic risk in adolescents. Ann Hum Biol 2015;42:70–5.
[23] Lek N, Yan W, Zhang Y, et al. Indices of central and general obesity and cardiometabolic risk among adolescents in three ethnic groups in northwest China. Ann Hum Biol 2015;4460:1–7.
[24] Tian S, Zhang X, Xu Y, et al. Feasibility of body roundness index for identifying a clustering of cardiometabolic abnormalities compared to BMI, waist circumference and other anthropometric indices: The China Health and Nutrition Survey, 2008 to 2009. Medicine (Baltimore) 2016; 95:e4642.
[25] Zhao Q, Zhang K, Li Y, et al. Capacity of a body shape index and body roundness index to identify diabetes mellitus in Han Chinese people in northeast China: A cross-sectional study. Diabet Med 2018;35: 1580–7.
[26] Bloch KV, Szklo M, Kuschnir MCC, et al. The study of cardiovascular risk in adolescents - ERICA: Rationale, design and sample characteristics of a national survey examining cardiovascular risk factor profile in Brazilian adolescents. BMC Public Health 2015;15:1–10.
[27] Bloch KV, Klein CH, Szklo M, et al. Erica: Prevalences of hypertension and obesity in Brazilian adolescents. Rev Saude Publica 2016;50:1s–12s.
[28] Associação Brasileira de Empresas de Pesquisas (ABEP). Critério de Classificação Econômica Brasil. São Paulo: ABEP; 2013. p. 5.
[29] Onis M, Onyango AW, Borghi E, et al. Developement of a WHO growth reference for school-aged children and adolescents. Bull World Health Organ 2007;85:660–7.
[30] National High Blood Pressure Education Program. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and

adolescents. No. 5. Bethesda (MD): US Department of Health and Human Services, National Institutes of Health, National Heart, Lung, and Blood Institute, National Hight Blood Pressure Education Program; 2005. p. 60.
[31] Simão AF, Precoma DB, Andrade JP, et al. I Diretriz Brasileira de Prevenção cardiovascular. Sociedade Brasileira de Cardiologia 2013;101.
[32] Alberti SG, Zimmet P. The IDF consensus definition of the metabolic syndrome in children and adolescents. Int Diabetes Fed 2007;24.
[33] Borges LRS. Medidas de Acurácia Diagnóstica na Pesquisa cardiovascular. Int J Cardiovasc Sci 2016;29:218–22.
[34] López-Ratón M, Rodríguez-Álvarez MX, Suárez CC, et al. OptimalCutpoints: An *R* Package for selecting optimal cutpoints in diagnostic tests. J Stat Softw 2014;61.
[35] Gu Z, Li D, He H, et al. Body mass index, waist circumference, and waist-to-height ratio for prediction of multiple metabolic risk factors in Chinese elderly population. Sci Rep 2018;8:8–13.
[36] Freedman DS, Kahn HS, Mei Z, et al. Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents. Am J Clin Nutr 2007;86:33–40.
[37] Klein S, Allison DB, Heymsfield SB, et al. Waist circumference and cardiometabolic risk. Diabetes Care 2007;30:1647–52.
[38] Ribeiro-Silva RC, Florence TCM, Conceição-Machado MEP, et al. Indicadores antropométricos na predição de síndrome metabólica em crianças e adolescentes: Um estudo de base populacional. Rev Bras Saúde Matern Infant 2014;14:173–81.
[39] Perkins NJ, Schisterman EF. The inconsistency of “optimal” cutpoints obtained using two criteria based on the receiver operating characteristic curve. Am J Epidemiol 2006;163:670–5.
[40] Morandi A, Miraglia Del Giudice E, Martino F, et al. Anthropometric indices are not satisfactory predictors of metabolic comorbidities in obese children and adolescents. J Pediatr 2014;165:1178–1183.e2.