Title Page

Title: Identifying the best body weight-status index associated with metabolic risk in youth

Running title: Weight-status index and metabolic risk

Authors: Thayse Natacha Gomes[1,2], Alan Nevill[3], Peter T. Katzmarzyk[4], Sara Pereira[1], Marcos Moura dos Santos[5], Rojapon Buranarugsa[6], Fernanda dos Santos[7], Michele Souza[8], Raquel Chaves[9], José Maia[1]

[1] CIFI[2]D, Faculty of Sport, University of Porto, Porto, Portugal
[2] Department of Physical Education, Federal University of Sergipe, Brazil
[3] Faculty of Education, Health and Wellbeing, University of Wolverhampton, United Kingdom
[4] Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA
[5] Department of Physical Education, University of Pernambuco, Recife-PE, Brazil
[6] Department of Physical Education, Faculty of Education, Khon Kaen University, Khon Kaen, Thailand
[7] Department of Physical Education, Federal University of Viçosa, Viçosa-MG, Brazil
[8] Centre of Sports, Federal University of Santa Catarina, Florianópolis-SC, Brazil
[9] Federal University of Technology-Paraná, Curitiba-PR, Brazil

Corresponding author:
Thayse Natacha Gomes, PhD
CIFI[2]D, Faculty of Sport, University of Porto, Porto, Portugal
Rua Dr Plácido Costa, 91
4200-450 – Porto, Portugal
Phone (351) 220 728 248
Email: thayse_natacha@hotmail.com

Conflict of interest
The authors declare no conflict of interest

Abstract

This study investigated the association of six different anthropometric markers with metabolic syndrome to find the most suited to predict children at risk. Sample comprises 1324 Portuguese youth (701 girls, 623 boys), aged 10-17 years. Six anthropometric markers were included: body mass index (BMI), BMI z-score, tri-ponderal index (TPI), waist circumference (WC), WC/height ratio (WC/H), and WC/H adjusted ratio (WC/H_{adj}). A standardized metabolic risk score (zMR) was computed by summing of standardized values for fasting glucose, triglycerides, high density lipoprotein cholesterol, and mean arterial blood pressure. The associations between zMR and anthropometric markers were assessed using univariate and multivariate analyses. Receiver operating characteristic (ROC) curve analysis was used to identify the optimal values that best predict metabolic risk for each anthropometric marker. Among the studied predictors, BMI z-score, followed by BMI and WC were most highly associated with zMR, while WC/H_{adj} was the weakest predictor. ROC analyses showed significant AUCs for all markers, yet the discrimination was poor (AUCs from 0.60 to 0.68), with sensitivity ranging from 45.5% to 67.5% and specificity from 72.6% to 81.9%. The optimal cut-off values to predict metabolic risk were 1.62, 23.1 kg/m^2, 71.0 cm, 18.0 kg/m^3, 0.47, and 0.50, for BMI z-score, BMI, WC, TPI, WC/H, and WC/H_{adj}, respectively. BMI z-score, followed by BMI and WC, ~~showed to be~~were the most relevant anthropometric markers to predict metabolic risk in youth; while WC/H_{adj} was the worst predictor. Results suggest that anthropometric markers should continue to be used as clinical tools to identify youth at risk.

Keywords: anthropometric indicators; metabolic syndrome; children; adolescents

INTRODUCTION

Paediatric obesity is associated with a variety of metabolic health problems such as impaired glucose metabolism, high blood pressure, dyslipidemia and metabolic syndrome in both childhood and adolescence in addition to adulthood,[1,2] in addition to increased morbidity and mortality in later life. Thus, it is very important to identify youth at risk for obesity-related co-morbidities such as the metabolic syndrome.

Anthropometric measurements are widely used to assess weight status, especially body mass index (BMI) and waist circumference (WC), with different health organizations suggesting their use to identify obesity-related metabolic risk.[3-6] However, some criticism exists regarding their use because there is no worldwide consensus regarding cut-points that could be used independent of ethnicity and sex.[3,7,8] For example, it is well known that BMI is not an indicator of relative fat distribution[9] and that BMI and WC cut-points are age- and sex-specific.[4,5] Accordingly, search has begun for a simple indicator to access obesity-related metabolic risks that should be practical and cost-effective to measure, more sensitive than BMI and WC, and with a universal cut-point for both sexes and subjects of different ethnic groups. Some have suggested the WC/height (WC/H) ratio as an indicator of obesity-related health risks, hypothesizing that since shorter subjects tend to have a higher risk of developing abnormalities (metabolic syndrome and related diseases[10,11]), height should be taken into account when WC is used as a putative obesity marker.[12] Some studies among adults have demonstrated that the WC/H index is useful as a screening tool for obesity and related metabolic disorders,[7,13,14] and a cut-point of 0.5 seems to be a suitable boundary value to identify subjects at risk for metabolic disorders, independent of sex and ethnicity.[7,13]

Contrary to adult data, available results in children and adolescents are inconclusive,[15-17] with some studies reporting similar results as in adults, i.e. WC/H being a better predictor of risk for metabolic disorders,[15] while others did not find statistically significant differences among WC/H index and BMI or WC.[16,17] Notwithstanding this inconsistency, the use of WC/H as a putative anthropometric health marker in youth is important because children and adolescents undergo significant body shape transformations due to growth, developmental, and maturational processes.[18] Hence, adjusting WC for their stature could remove the bias related to these processes (especially when considering children with the same WC but with differences in their heights). Furthermore, it is well known that children do not grow in the same way, nor even with the same intensity because of variation in their maturational timing and tempo.[18] Because of this, a WC/H ratio adjusted (WC/H_{adj}) using the allometric approach which takes into consideration changes in body size by sex and age, may be a more suitable and accurate index to predict metabolic risk in youth than WC/H. For example, Nevill et al.[19] demonstrated that scaling WC to body size was more accurate than traditional methods of predicting metabolic risk indicators in adults. Further, It was recently suggested that the tri-ponderal index (TPI) should be a more accurate surrogate of body fat,[20] and since body fat is strongly related to metabolic risk, the TPI could more suitably describe the association with metabolic risk indicators in the paediatric population. Thus, the purpose of the present study was to investigate the association of six different anthropometric markers (BMI, BMI z-score, TPI, WC, WC/H, and WC/H_{adj}) with metabolic syndrome in children and adolescents to find the best suited index to predict metabolic risk.

METHODS

Sample

The sample comprises 1324 adolescents (701 girls, 623 boys), aged 10-17 years from the North and Central regions of mainland Portugal, as well as from the Azores Islands. Since the number of adolescents aged ≥15 years was small, those aged 16-17 were combined with 15 yr olds. Therefore, 6 age groups will be considered (10 yrs, 11 yrs, 12 yrs, 13 yrs, 14 yrs, and 15+ yrs). The sample originates from three research projects (*The Oporto Mixed-Longitudinal Growth, Health and Performance Study*; *The Portuguese Sibling Study on Growth, Fitness, Lifestyle and Health*; *Active Vouzela*), and adolescents were recruited from their schools. All projects were in accordance with the Declaration of Helsinki and all procedures were approved by the University of Porto Ethics Committee as well as from schools' authorities. Parental/legal guardians' written informed consent was obtained for all subjects.

Anthropometry

Standing height, weight, and WC were measured according to standardized procedures,[21] with subjects wearing light clothes, without shoes or socks. Standing height was measured using a portable stadiometer (Holtain Ltd, UK) to the nearest 0.1 cm; weight was measured with a portable bioelectrical impedance scale (TANITA BC-418 MA Segmental Body Composition Analyser, Tanita Corporation, Japan), with a precision of 0.1 kg; WC was measured with a non-elastic tape (Sanny, American Medical of Brazil, Brazil) at the smallest circumference between the lowest rib and the superior iliac crest, to the nearest 0.1 cm, while subjects were standing erect with a relaxed abdominal muscle, and the measurement was taken in the end of a normal expiration.

Five anthropometric indices were used to define weight status as follows: BMI was computed using the standard formula weight(kg)/height(m)^2; BMI z-scores were established using WHO age- and sex-specific reference data;[4] TPI was computed as weight(kg)/height(m)^3; WC/H was calculated by dividing WC(cm) by height(cm); WC/H_{adj}, was determined by dividing WC(cm) by height^b(cm) (*b* value is explained in the statistical analysis subsection as well as in the results section).

Metabolic risk indicators

Based on the current definition for the metabolic syndrome,[3,22] the metabolic risk indicators, used in the present study, included fasting glucose, triglycerides, high density lipoprotein cholesterol (HDL-C), and mean arterial blood pressure (MAP). Resting systolic (SBP) and diastolic (DBP) blood pressures were measured with an automatic digital Omron sphygmomanometer (Omron M6 HEM 7001-E, Omron Healthcare), and all subjects were at rest for at least 10 minutes before the first measurement. Three measurements were taken with a 3-minute interval[23] between measurements, and the mean values were used in analyses. MAP was computed as follows: MAP=[(SBP-DBP)/3 + DBP]. Fasting measurements of glucose, triglycerides, and HDL-C were obtained from finger-stick blood samples collected after at least 10-12 hours of overnight fasting, and were analysed with a Cholestech LDX point-of-care analyser (Cholestech Corporation, Hayward, USA) using standardized procedures from the manufacturer[24]. Each metabolic risk indicator was log transformed, and then they were converted to z-scores. A standardized metabolic risk score (zMR), not adjusted for age or sex, was computed by summing the four metabolic risk indicator z-scores (with the HDL-C z-score previously multiplied by -1). The lower the zMR the better the metabolic risk score. Only youth with complete information for the metabolic indicators were included in the analyses.

Data analysis

Descriptive statistics are means and standard deviations (SD). Following the methods of Nevill et al.[19] such that a body shape index for WC was to be independent of standing height, the following allometric power function was used:

$$WC = a \cdot H^{b} \cdot \varepsilon,$$

where "a" and "b" are the scaling constants and scaling exponents for WC, respectively, and ε is the ratio error, that assumes that the error will increase in proportion to body size (in this case height, H). Age and sex were introduced in the model by allowing the parameter "a" to vary for each sex and age group to accommodate the likelihood that WC may raise and then peak during the adolescent period. This model was linearized with a log-transformation, and ANCOVA was used to estimate the height exponent for WC having controlled for both age group and sex.

To explore the association between zMR and the six anthropometric indicators of weight status (BMI, BMI z-score, TPI, WC, WC/H, WC/H_{adj}), two analyses were done. First, six MANCOVAs (using the metabolic risk indicators as multivariate independent variables), introducing each anthropometric indicator of weight status as separate covariates, as well as sex and age groups as fixed factors, were performed. Secondly, to determine the relationship between zMR with the weight status indicators, six ANCOVAs were performed, using each anthropometric indicator as separate covariates, with sex and age groups as fixed factors. Eta squared (η^2) was used as a measure of effect size. Receiver operating characteristics (ROC) curve analysis was also performed in order to identify the optimal values, for each anthropometric variables, that best predict metabolic risk in children. The area under the curve (AUC) was also computed using +2 SD as a criterion to discriminate children "at risk"; an AUC of 1 indicates perfect predictive ability, and an AUC of 0.5 indicates no greater predictive ability than by chance alone. The following criteria were used to classify AUC values: 0.9-1, excellent; 0.8-0.9, fair; 0.6-0.7, poor; 0.5-0.6, fail.[25,26] The Youden index[27] was used to determine the "optimal value", for each anthropometric measure, to determine risk for metabolic risk [maximum *J* value (sensitivity + specificity)]. Given that sensitivity is the true positive fraction and specificity is the true negative fraction, our aim was to find a cutoff point that maximizses both simultanieously. All analyses were done in SPSS 23, and the significance level was set at 0.05.

RESULTS

Descriptive statistics (mean±standard deviation) are summarized in Table 1. Except for BMI z-score, TPI and WC/H, all mean values for anthropometry increase with advancing age in both boys and girls. Based on criteria of the WHO (add reference), the proportion of the sample who were normal weight, overweight and obese was 63.1%, 27.7%, and 9.1%, respectively,

Insert Table 1 about here

The allometric power model for WC showed a significant height exponent that varies according to age group. This means that the body-shape index for WC to be independent for stature needs to be adjusted by the allometric exponent varying systematically with age. Yet, given that some of these exponents were similar in adjacent age groups, a new age readjustment was calculated and three age groups were formed (10-12 yrs, 13-14 yrs, 15+ yrs). For each one of these age-groups, a specific equation was used, since the stature exponents were found to vary with age (Table 2): $WC \cdot H^{-1}$ for children aged 10-12 yrs; $WC \cdot H^{-0.8}$ for children aged 13-14 yrs; and $WC \cdot H^{-0.5}$ for children aged 15 yrs.

Insert Table 2 about here

Table 3 shows results for the MANCOVAs regarding the contributions of the anthropometric indicators to the zMR, controlling for sex and age group. The Wilks lambda results range from 0 to 1, and the lower it is, the stronger the relationship is: BMI z-score, followed by BMI, shows the smallest Wilks' lambda meaning that it is the highest associated variable with the metabolic syndrome set of indicators.

Insert Table 3 about here

ANCOVA results for the prediction of zMR from each anthropometric variable are presented in Table 4. Similar to results in Table 3, BMI z-score was the best predictor of zMR, followed by BMI, TPI, WC and WC/H. The WC/H_{adj} was the weakest zMR predictor in youth.

Insert Table 4 about here

Table 5 and Figure 1 show the ROC analysis results for the anthropometric variables to predict metabolic risk. Based on the cut-off of +2 SD, 18.6% of the sample fell into the "at risk" group. All AUCs were statistically different than 0.5,~~satisfactory, but poor,~~ ranging from 0.60 (WC/height ratio adjusted) to 0.68 (BMI), with sensitivity and specificity ranging from 45.5% to 67.~~48~~5% and from 72.6~~3~~% to 82.~~6~~7%, respectively. ~~(sensitivity: BMZ-Z, 45.71%; BMI, 45.53%; WC, 53.25%; TPI, 45.53%; WC/H, 45.53%; WC/Hadj, 67.48%. Specifity: BMI-Z, 82.67%; BMI, 81.91%; WC, 72.63%; TPI, 81.26%; WC/H, 78.01%; WC/Hadj, 53.33%).~~ The optimal values to predict metabolic risk in children were 1.62, 23.~~08~~1 kg/m^2, 71~~0~~.~~95~~0 cm, 1~~7~~8.0~~.98~~ kg/m^3, 0.47, and 0.50, for BMI z-score, BMI, WC, TPI, WC/H ratio, and WC/H_{adj}, respectively.

Insert Table 5 about here

Insert Figure 1 about here

Discussion

Comment [PTK1]: I found this in an old table, is it correct?

Comment [NAM(2]: Not sure how the AUC can be both satisfactory and poor at the same time?

Comment [PTK3]: I agree I would not present this since it repeats the table. If you do, only to 1 decimal place.

Comment [NAM(4]: I agree, repeated in the Table.

From the six anthropometric indicators investigated in this study, BMI (z-score and ~~in~~ raw values) and WC were most highly associated with metabolic risk scores in children, while WC/H_{adj} showed a somewhat lower association. These results highlight the importance of BMI, especially BMI z-score, and WC as health markers in children. Different health organizations,[3] as well as previous reports,[28,29] identified BMI and/or WC as putative indicators of adiposity within the metabolic syndrome criteria, but the use of BMI z-score is limited, notwithstanding its relevance as an optimal marker to predict excess weight in children.[30] However, previous studies investigated its role in predicting metabolic syndrome in the paediatric population showed that BMI z-score was not a significant predictor of youth metabolic risk.[31,32] In the present study our results go in the opposite direction revealing BMI z-score as the best indicator to predict metabolic risk in Portuguese children: This suggests that its use can be extended from predicting excess weight to metabolic risk.

As regards to BMI, and according to available data, its use as an health risk marker is not without controversy,[9] because it cannot discriminate between lean and fat tissue. Nevertheless, other studies have reinforced BMI as a relevant health risk marker in paediatric populations.[33,34] For example, Bauer et al.[33] investigated the utility of BMI, WC and WC/H to discriminate adolescents with and without cardiometabolic risk. Their results indicated that, notwithstanding the importance of WC and WC/H as screening tools, BMI was the best discriminator of cardiometabolic risk. Further, Harrington et al.[34] concluded that the 95th CDC BMI percentile is useful to predict elevated levels of visceral adipose tissue, fat mass and cardiometabolic risk factors in youth. Our results are in line with this evidence, i.e., BMI was associated with metabolic risk in this sample of children and adolescents.

It is commonly suggested that WC is not only a useful marker of adiposity, but also a relevant metabolic risk factor.[3] Similar to what has been reported for BMI, there is controversy related to using WC as a marker of adiposity. For example, there is evidence that WC is an effective surrogate of trunk adiposity in youth.[35] Yet, its usefulness in the assessment of central obesity in children and adolescents is debatable because of different cut-points being highly variable among studies which are dependent on sample characteristics.[36] In the present report, WC showed similar results with metabolic risk score as BMI, but somewhat higher than the other indicators, suggesting that it can also be a significant predictor of metabolic risk in children. These results reinforce the suggestion that these two health indicators (BMI and WC) perform similarly in their association with metabolic risk in youth, highlighting their relevance when considering youth health.

One of the major criticisms associated with using BMI and WC as clinical markers of children's and adolescents' health status is related to the absence of universal cut-points. It is well known that available cut-points are sex, age-, and also ethnic-specific, which not only limits comparisons across studies, but may also restrain their clinical use to accurately predict youth at risk. This is why there has been a search for new anthropometric markers, and the WC/height ratio was suggested. As suggested by Ashwell and Hsieh,[7] this index possibly has advantages relative to BMI, and even to WC itself, because a universal cut-point could be derived and used independently of age, sex or ethnicity. Furthermore, it is also been suggested that WC/height ratio is more sensitive to early warnings of health risk than BMI or WC.[14] In adults, there is some evidence suggesting the relevance of WC/Height ratio to screen metabolic risk factors, and also indicating its superiority over BMI and WC [13,14]. Yet, results in children are inconclusive.[16,33] For example, data from European children[16] suggested that the effect sizes of BMI, WC, and WC/H with cardiometabolic risk factors are similar, and also that their precision to screen for increased risk is low. Additionally, Bauer et al.[33] assessed the utility of BMI, WC, and WC/H to discriminate adolescents with and without cardiometabolic risk, and showed that WC/H or WC were better screening tools than BMI for identify cardiometabolic risk. On the contrary, a literature review by Yoo[15] concluded that, in youth, WC/H has similar power as BMI or WC in identifying subjects with increased cardiometabolic risk.

Our results indicate that WC/H (both unadjusted or adjusted) had the worst performance in predicting zMR in youth. Although this finding is commensurate with previous results,[33] they were partially unexpected, especially because the WC/Height ratio adjusted for body size showed the lowest association. As suggested by Nevill et al.[37] scaling youth WC for differences in their body size can provide relevant insights related to WC growth and development in youth, meaning that its effect on metabolic risk could be enhanced; in addition, in a study of adults,[19] it was shown that $WC/H^{0.5}$ was the best anthropometric marker associated with metabolic risk. However, in our sample such an indication did not occur, because the WC/Height ratio did not perform better than BMI in association with metabolic risk scores, while the WC/H adjusted was the weakest indicator, in opposition to previously reported data. This may mean that, in children and adolescents, abdominal adiposity most strongly marked by WC/H than by WC alone is not so relevant for metabolic risk than “general” adiposity/excess weight expressed by BMI. It is also important to note that, as regards to TPI, we were not able to find any study that investigated its role on the prediction of metabolic risk in youth. Anyhow, it did not perform as well as BMI in risk expectation.

Results from ROC analysis showed analogous AUC values among our variables, but BMI z-score showed the highest value (0.68) and WC/H_{adj} the lowest (0.60). Although these results were statistically significant, we should nevertheless classify them as “poor” predictors because all AUCs were below 0.70. Nevertheless, Harrington et al.[34] found similar AUC results for the optimal BMI percentile to predict ≥2 cardiometabolic risk factors in youth. Additionally, similar AUC results for BMI, WC and WC/H as predictors for metabolic risk, or metabolic risk indicators separately, were reported by other studies.[16,33,38] However, Zhou et al.[39] investigated the role of WC/H, BMI, and WC as screening tool for Chinese youth metabolic syndrome, and found AUC values higher than 0.87. Once more, available results related to the effectiveness of anthropometric measurements, or ratios, in predicting metabolic risk in children are not conclusive. Furthermore, our results also showed the lowest sensitivity for BMI (similar to TPI and WC/H) of 45.5%, meaning that only 45.5% of youth would be correctly classified as at risk, while about 28% (specificity value of 81.9%) would be incorrectly classified as at risk. Overall, the anthropometric markers studied showed low sensitivity values, highlighting their reduced power to correctly classify children and adolescents as at risk. On the contrary, higher specificity values revealed that they have a higher power to identify youth that are not at risk. The exception is WC/H_{adj} which had low values for both, sensitivity and specificity.

The use of anthropometric markers to identify children with increased metabolic risk has been systematically studied,[16,40,41] and though results suggest its usefulness, low sensitivity values were also reported. This scenario reinforces that although their use may be valuable to identify young subjects with no metabolic risk, they also tend to misclassify those at risk. Further, this may also entail that direct measurements of metabolic risk indicators may be essential, instead of anthropometric information, in the identification of children and adolescents at risk. In the present study, we chose to use metabolic risk factors that are often used in defining the metabolic syndrome. The degree to which our results would be different if we had chosen other risk factors such as fasting insulin, CRP, etc. are not known. Given the variability across studies in the selection of risk factors to identify metabolic risk, this makes direct comparisons of results across studies difficult.

This study is not without limitations. First, despite the fact that our sample combined data from different Portuguese regions, it is not representative of the country as a whole, and the results may not be generalizable.should not be generalized. Second, the use of zMR, instead of a dichotomous clinical classification of "metabolic syndrome" per se may have contributed to the low effectiveness in predicting metabolic risk in youth, since the cut-point of +2 SD is not a universal criterion. However, given the age range of the sample, and the fact that there is no consensus regarding cut-points to identify metabolic syndrome in youth, we used an approach that is consistent with previous research. Third, we did not have access to biological maturation data that could also be used in refining our analysis as it can be considered a confounder in the age range of our sample. Fourthly, the lack of information regarding children's physical activity, sedentary behaviour, and nutritional habits limits our ability to statistically adjust for these potentially confounding variables. However, our analysis focuses on the clinical utility (i.e. ROC analysis) of the anthropometric variables, and it is also difficult to control for behavioural factors in clinical settings. Yet, this information is not easily available given ethical and practical considerations.

In conclusion, the present study showed that, in spite of its relevance to detect metabolic risk in adults, the WC/H, even when adjusted to body size, is not a better marker than BMI z-score, or even BMI and WC to predict metabolic risk in children and adolescents. Furthermore, in general, anthropometric cut-points to identify youth at risk showed low sensitivity, i.e., with a low percentage of children being correctly classified as at risk. Yet, BMI z-score and BMI were the most relevant anthropometric markers linked with children and adolescents' metabolic risk. It is a non-invasive indicator, used worldwide, and with a lower error when compared to WC given that different measurement protocols exist and possible physical constraints regarding its measurement may ensue. Both BMI z-score and BMI can and should be used in clinical and epidemiological research to identify youth at risk and, especially, those without risk.

Perspective

The present study showed that BMI z-score and BMI seem to be ~~the~~ highly reliable anthropometric markers to identify metabolic risk in youth. This is important information for future research and/or intervention studies focusing in preventing metabolic risk in paediatric population, given that: (1) height and weight are non-invasive measurements that can be obtained in almost all subjects in simple and accurate ways; (2) even if they are objectively measured, parents/legal guardians can provide them with no special constraints for the study information quality. Either way, higher sample sizes will be easily obtained, without increasing costs, and in all likelihood will provide significant information linked to metabolic risk in paediatric population. Furthermore, youth lifestyles, namely their health-enhancing physical activity/sports involvement as well as their health-related physical fitness, are prone to be tied with youth height and weight which, in turn, will affect their metabolic risk.

Acknowledgements

The Portuguese Foundation of Science and Technology (individual grant SFRH/BOD/1231452016).

References

1. 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.* 2010;122(16):1604-1611.

2. Taksali SE, Caprio S, Dziura J, et al. High visceral and low abdominal subcutaneous fat stores in the obese adolescent: a determinant of an adverse metabolic phenotype. *Diabetes.* 2008;57(2):367-371.

3. Zimmet P, Alberti KG, Kaufman F, et al. The metabolic syndrome in children and adolescents - an IDF consensus report. *Pediatr Diabetes.* 2007;8(5):299-306.

4. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ.* 2007;85(9):660-667.

5. Fernandez JR, Redden DT, Pietrobelli A, Allison DB. Waist circumference percentiles in nationally representative samples of African-American, European-American, and Mexican-American children and adolescents. *J Pediatr.* 2004;145(4):439-444.

6. World Health Organization. *Waist circumference and waist-hip ratio: Report of a WHO expert consultation.* Geneva: WHO; 2011.

7. Ashwell M, Hsieh SD. Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *Int J Food Sci Nutr.* 2005;56(5):303-307.

8. Freedman DS, Wang J, Maynard LM, et al. Relation of BMI to fat and fat-free mass among children and adolescents. *Int J Obes (Lond).* 2005;29(1):1-8.

9. Yajnik CS, Yudkin JS. The Y-Y paradox. *Lancet.* 2004;363(9403):163.

10. Nuesch E, Dale C, Palmer TM, et al. Adult height, coronary heart disease and stroke: a multi-locus Mendelian randomization meta-analysis. *Int J Epidemiol.* 2016;45(6):1927-1937.

11. Fujita Y, Kouda K, Nakamura H, Iki M. Inverse association between height increase and LDL cholesterol during puberty: A 3-year follow-up study of the Fukuroi City. *Am J Hum Biol.* 2016;28(3):330-334.

12. Schneider HJ, Klotsche J, Silber S, Stalla GK, Wittchen HU. Measuring abdominal obesity: effects of height on distribution of cardiometabolic risk factors risk using waist circumference and waist-to-height ratio. *Diabetes Care.* 2011;34(1):e7.

13. Browning LM, Hsieh SD, Ashwell M. A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0.5 could be a suitable global boundary value. *Nutr Res Rev.* 2010;23(2):247-269.

14. Ashwell M, Gunn P, Gibson S. Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obes Rev.* 2012;13(3):275-286.

15. Yoo EG. Waist-to-height ratio as a screening tool for obesity and cardiometabolic risk. *Korean J Pediatr.* 2016;59(11):425-431.

16. Sardinha LB, Santos DA, Silva AM, Grontved A, Andersen LB, Ekelund U. A Comparison between BMI, Waist Circumference, and Waist-To-Height Ratio for Identifying Cardio-Metabolic Risk in Children and Adolescents. *PLoS One.* 2016;11(2):e0149351.

17. Ma C, Wang R, Liu Y, et al. Performance of obesity indices for screening elevated blood pressure in pediatric population: Systematic review and meta-analysis. *Medicine (Baltimore).* 2016;95(39):e4811.

18. Malina R, Bouchard C, Bar-Or O. *Growth, maturation and physical activity.* 4ª ed. Illinois: Human Kinetics Books; 2004.

19. Nevill AM, Duncan MJ, Lahart IM, Sandercock GR. Scaling waist girth for differences in body size reveals a new improved index associated with cardiometabolic risk. *Scand J Med Sci Sports.* 2017;27(11):1470-1476.

20. Peterson CM, Su H, Thomas DM, et al. Tri-Ponderal Mass Index vs Body Mass Index in Estimating Body Fat During Adolescence. *JAMA Pediatr.* 2017;171(7):629-636.

21. Lohman T, Roche A, Martorell E, eds. *Anthropometric standardization reference manual.* Champaign: Human Kinetics; 1988.

22. Alberti KG, Zimmet P, Shaw J. Metabolic syndrome--a new world-wide definition. A Consensus Statement from the International Diabetes Federation. *Diabet Med.* 2006;23(5):469-480.

23. 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(2 Suppl 4th Report):555-576.

24. LDX C. *The accuracy and reproducibility of a rapid, fingerstick method for measuring a complete lipid profile is comparable to a reference laboratory method (b).* Cholestec Corporation; 2003.

25. Craig E, Bland R, Ndirangu J, Reilly JJ. Use of mid-upper arm circumference for determining overweight and overfatness in children and adolescents. *Arch Dis Child.* 2014;99(8):763-766.

26. Zou KH, O'Malley AJ, Mauri L. Receiver-operating characteristic analysis for evaluating diagnostic tests and predictive models. *Circulation.* 2007;115(5):654-657.

27. 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(7):670-675.

28. De Ferranti SD, Gauvreau K, Ludwig DS, Newburger JW, Rifai N. Inflammation and changes in metabolic syndrome abnormalities in US adolescents: Findings from the 1988-1994 and 1999-2000 National Health and Nutrition Examination Surveys. *Clinical Chemistry.* 2006;52(7):1325-1330.

29. Cook S, Weitzman M, Auinger P, Nguyen M, Dietz WH. Prevalence of a metabolic syndrome phenotype in adolescents: findings from the third National Health and Nutrition Examination Survey, 1988-1994. *Arch Pediatr Adolesc Med.* 2003;157(8):821-827.

30. Inokuchi M, Matsuo N, Takayama JI, Hasegawa T. BMI z-score is the optimal measure of annual adiposity change in elementary school children. *Ann Hum Biol.* 2011;38(6):747-751.

31. Mendoza JA, Nicklas TA, Liu Y, Stuff J, Baranowski T. General versus central adiposity and relationship to pediatric metabolic risk. *Metab Syndr Relat Disord.* 2012;10(2):128-136.

32. Wicklow BA, Becker A, Chateau D, Palmer K, Kozyrskij A, Sellers EA. Comparison of anthropometric measurements in children to predict metabolic

syndrome in adolescence: analysis of prospective cohort data. *Int J Obes (Lond).* 2015;39(7):1070-1078.

33. Bauer KW, Marcus MD, El ghormli L, Ogden CL, Foster GD. Cardio-metabolic risk screening among adolescents: understanding the utility of body mass index, waist circumference and waist to height ratio. *Pediatr Obes.* 2015;10(5):329-337.

34. Harrington DM, Staiano AE, Broyles ST, Gupta AK, Katzmarzyk PT. BMI percentiles for the identification of abdominal obesity and metabolic risk in children and adolescents: evidence in support of the CDC 95th percentile. *Eur J Clin Nutr.* 2013;67(2):218-222.

35. Taylor RW, Jones IE, Williams SM, Goulding A. Evaluation of waist circumference, waist-to-hip ratio, and the conicity index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3-19 y. *Am J Clin Nutr.* 2000;72(2):490-495.

36. Magalhaes EI, Sant'Ana LF, Priore SE, Franceschini Sdo C. [Waist circumference, waist/height ratio, and neck circumference as parameters of central obesity assessment in children]. *Rev Paul Pediatr.* 2014;32(3):273-281.

37. Nevill AM, Duncan MJ, Lahart IM, Davies P, Ramirez-Velez R, Sandercock G. Scaling children's waist circumference for differences in body size. *Am J Hum Biol.* 2017.

38. Kuba VM, Leone C, Damiani D. Is waist-to-height ratio a useful indicator of cardio-metabolic risk in 6-10-year-old children? *BMC Pediatr.* 2013;13:91.

39. 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.

40. Adegboye AR, Andersen LB, Froberg K, Sardinha LB, Heitmann BL. Linking definition of childhood and adolescent obesity to current health outcomes. *Int J Pediatr Obes.* 2010;5(2):130-142.

41. 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: the Bogalusa Heart Study. *Am J Clin Nutr.* 2007;86(1):33-40.

Figure Legends

Figure 1. ROC curves for BMI z-score, BMI, WC, TPI, WC/H, and WC/H_{adj}