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Waist circumference measurement site does not affect relationships with visceral adiposity and cardiometabolic risk factors in children

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Abstract

Background—Different waist circumference (WC) measurement sites are used in clinical and epidemiological settings.

Objectives—To examine differences in WC measurement at four anatomic sites and how each WC measurement relates to visceral adipose tissue (VAT) and cardiometabolic risk factors in children.

Methods—371 white and African American children aged 5–18 years had WC measured at four sites: minimal waist, midpoint between the iliac crest and the lowest rib, superior border of the iliac crest, and the umbilicus. Abdominal VAT was measured using magnetic resonance imaging, and cardiometabolic risk factors were defined using NHLBI guidelines. Relationships between WC sites and VAT and risk factors were explored in each race-by-sex group.

Results—All WC sites were highly correlated (r = 0.97 to 0.99). Differences in absolute mean WC values existed in all race-by-sex groups, and this affected the prevalence of high WC (≥90th percentile). Values were lowest for minimal waist and highest for umbilicus. Age-controlled partial correlations between WC and VAT were 0.81 to 0.89 (all $p<0.001$) and between WC and cardiometabolic risk factors were −0.24 to −0.41 and 0.19 to 0.52 (all $p<0.05$).

Conclusions—While the absolute values of WC at four anatomic locations differed, the relationships between WC values and both VAT and cardiometabolic risk factors were similar within all race-by-sex groups.

Introduction

Waist circumference (WC) is a simple and inexpensive clinical tool for the assessment of pediatric adiposity and obesity-related health risks (1). A variety of anatomic landmarks are used for the measurement of WC (2,3); however it is unclear whether the location of the measurement site alters the relationship between WC and abdominal adiposity as it relates to cardiometabolic risk assessment, particularly in children.

A large variation in protocols for the measurement of WC exists with most falling into four broad categories: the narrowest waist, at the midpoint between the lowest rib and iliac crest,

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immediately above the iliac crest (3) and at the level of the umbilicus. The iliac crest has been recommended for use in adults (1,4) and children (5) and has been used in large scale surveillance studies (6,7). The World Health Organization has recommended the use of the mid-point between the iliac crest and lowest rib (8). A limited number of studies have documented differences in the absolute values of WC measurements across these common sites, particularly in females (3,9–16). However, many of these studies were based on adults (9,12,15), had a low sample prevalence of overweight/obesity (14), or used a single ethnicity (9,10,13,14,16). Reproducibility has been high across various WC sites (3,9,13) but has not been investigated in a large pediatric sample. Furthermore, few studies (14,15) have related WC measurements at different sites to abdominal visceral adipose tissue (VAT), measured with magnetic resonance imaging (MRI), which is considered to be a gold standard. The limited evidence with regard to the differences in WC measured at various anatomic sites in children calls for appropriately powered studies in different ethnic groups. The difference between the absolute WC measurements at varied anatomical sites could affect the relationship between WC and VAT and cardiometabolic risk.

The aim of this analysis was to investigate differences in absolute WC measurements obtained from four commonly used anatomic sites in a biracial sample of children. Furthermore, we aimed to determine the relationship between each WC and VAT and cardiometabolic risk factors. The reproducibility of measurements at each site was also assessed.

Methods

Study Sample

Originally, 423 participants (ages 5–18 years) were enrolled in a cross-sectional study of factors related to abdominal adiposity. Recruitment occurred through study advertisements as well as through pediatrician's offices in the Baton Rouge area of Louisiana. Recruitment efforts attempted to balance the sample across race, sex, and body mass index (BMI) categories (normal weight, overweight and obese). Thirteen were excluded as their self-reported race was not white or African American (AA) while 26 participants did not have MRI, 12 did not have lab work and the VAT of one participant was >3 standard deviations above the group mean and was excluded. The final sample for this analysis consisted of 371 participants (95 white males, 80 AA males, 83 white females and 113 AA females). Parents/guardians of the participants provided signed informed consent and the children provided written assent. All study procedures were approved by the Pennington Biomedical Research Center Institutional Review Board.

Study Power and Sample Size Calculation

We estimated the sample sizes necessary to detect a difference between the two most extreme partial correlations between WC and VAT. Based on the literature, we anticipated our age-controlled partial correlation estimates to be in the range of 0.78–0.95 (17). Our power analysis corresponded to a one-sample t-test for mean = 0, using standard deviations for the comparison of two correlated correlations estimated according to Meng (18), and assuming a correlation of 0.98 between WC across the different measurement sites and VAT. The target sample size of 400 children was calculated to provide 80% power at effect sizes (absolute difference between the maximum and minimum correlation coefficients) of 0.05 to 0.10. In a retrospective power analysis, the analytic sample size of 371 children should provide sufficient power to detect differences of at least 0.08 among the partial correlations between WC at each of four measurement sites and VAT.

Anthropometry

Height and weight were measured by staff trained in anthropometry. Height was measured using a wall-mounted stadiometer after removal of shoes. Weight was measured using a digital scale after all outer clothing, heavy pocket items and shoes were removed. Height was recorded twice to the nearest 0.1 cm and weight was recorded twice to the nearest 0.1 kg. A third height or weight measurement was obtained if the first two measurements were greater than 0.5 cm or 0.5 kg apart respectively with the average of the two (or the two closest) used in the analysis. Body mass index (BMI) was calculated (weight in kg/height in m^2).

WC measurements were taken at the following anatomic sites: i) minimal waist (19), ii) midpoint between the iliac crest and the lowest rib (8), iii) superior border of the iliac crest (4) and iv) umbilicus (referred to by McCarthy et al. (20)). Specifically, the minimal waist was visually assessed as the smallest circumference between the lower end of the sternum (xiphoid process) and the umbilicus. For the midpoint, the iliac crest (upper border of the ilium on the mid-axillary line) and the inferior border of the lowest rib were palpated and marked. The distance between the two landmarks was measured and the midpoint was marked and used for tape measure placement. Participants were asked to expose the areas to be measured and were requested to stand in an upright position with feet together and arms relaxed at their sides. Measurements were made at the end of normal expiration with special attention to ensure that the anthropometric tape lay perpendicular to the long axis of the body and parallel to the floor. Each measurement was taken by one of three trained technicians. The measurements were taken twice and recorded to the nearest 0.1 cm with the average of each of the two (or the two closest) circumferences used in analysis (a third measurement was obtained if the first two measurements were greater than 0.5 cm apart).

Reliability of WC Measurements

Inter- and intra-tester reliability for WC measurements at four anatomical sites was assessed in a subsample of 31 participants (12 white males, 4 AA males, 11 white females and 4 AA females) using three technicians who measured the majority of the overall sample. As reliability may differ depending on sex, age and adiposity level, a range of ages (6.8 to 18.3 years) and BMI percentiles (6^{th} to 99^{th}) were used with 13 participants having a BMI at or above the Center for Disease Control and Prevention 90th percentile. For inter-tester reliability, WC measurements were taken on the same participant by two different technicians on the same visit, and intra-tester reliability was assessed using WC measurements taken on the same participant by the same technician on an average of 6 days apart (range 2 to 11 days). Intra-class correlation coefficients for inter-tester reliability were between 0.989 and 0.999 while intra-tester intra-class correlation coefficients for were between 0.983 and 0.994 (Table 1). No differences were seen between either of the reliability scores when the group was stratified by BMI (data not shown).

MRI

MRI scans were performed using a General Electric Signa Excite (3.0 Tesla; GE Medical Systems, Waukesha, WI) scanner. Participants lay motionless on the scanner table and an 8 channel torso-array coil was placed over their chest/abdomen area. A series of scans from the highest point of the liver to the bottom pole of the right kidney were acquired. Slice images were analyzed using the Analyze (CNSoftware, Rochester, MN) software package with each analyzed slice being 28 slices (4.78 cm) apart. VAT area was manually drawn by one trained technician and the number of pixels was multiplied by voxel width and height for each individual slice to compute VAT area (cm^2). The area from each individual slice was multiplied by the slice gap (4.78 cm), then multiplied by 0.000001 and finally multiplied by the voxel depth of that slice. This resulted in a VAT volume for each of the 5

to 8 slices. These volumes were then summed to calculate total volume of VAT (liters) for each participant. To test the reliability for quantifying VAT using MRI, the trained technician re-analyzed a random sub-set of 20 images at the L4-L5 slice (blinded). The mean coefficient of variation (CV) was 6.63 (SD = 6.35) for VAT area and correlation between the first and second analysis was 0.97. This CV was within the acceptable limits based on similar studies of pediatric cohorts (21–23)

Cardiometabolic Risk Factors

Blood pressure was measured using a standard mercury manometer using an appropriately sized cuff with the participant rested for 5 minutes in a quiet room. The measurement was taken twice and a third was taken if there was ≥10 mm/Hg difference. The average measurement was used in the analysis. Fasting blood samples were obtained from participants following an overnight fast. Serum triglycerides, high density lipoprotein cholesterol (HDL-C) and glucose concentrations were obtained from a Beckman Coulter DXC 600 (Brea, CA), with reagents from Beckman Coulter and Trinity (Fisher Scientific, Pittsburg, PA). The between-run coefficients of variation were 2.17% for glucose, 1.63% for triglycerides, and 1.76% for HDL-C. All clinical chemistry assays were conducted by the Pennington Biomedical Research Center Clinical Chemistry Laboratory which participates in the lipid standardization program of the Centers for Disease Control and Prevention.

The metabolic syndrome components from the NHLBI Integrated Guidelines were used for defining cardiometabolic risk (24). Dyslipidemia was defined as HDL-C ≤45 mg/dL and triglycerides ≥75 mg/dL (5–9 year-olds) or ≥90 mg/dL (10–18 year-olds). Hyperglycemia was defined as a fasting blood glucose ≥100 mg/dL. High blood pressure was defined as having a systolic *or* diastolic blood pressure ≥90^{th} percentile (25) for age, sex and height. The obesity risk factors from these guidelines (i.e. BMI and WC) were not included in defining metabolic risk. Participants with ≥2 cardiometabolic risk factors were considered to have elevated risk.

Statistical Analysis

Differences in absolute mean WC values within each race-by-sex group were explored using repeated measures ANOVA with Tukey post-hoc tests for multiple comparisons where appropriate. As VAT volume did not fit a normal distribution, it was log transformed. As WC increases with age, relationships between WC, logVAT and cardiometabolic risk factors were explored using Pearson partial correlations, controlling for age. The prevalence of high WC (≥90^{th} percentile) was determined using age- and sex-specific reference data for the United States (7). IBM SPSS V.20 (IBM Corp, Armonk, NY) was used for ICCs with data management and all other analyses conducted using SAS V.9.3 (SAS Institute Inc., Cary, NC).

Results

Participant characteristics, mean WC values for each anatomic site and sample prevalence of obesity and elevated cardiometabolic risk factors are shown in Table 2. The mean age for the overall sample was 12.3 (±3.5) years and the mean BMI was 23.2 (±6.8) kg/m^2. All WC measurement sites were significantly different ($p<0.05$) from each other for the overall sample and for white females. For white males and AA females, no significant difference was found between the sites at the iliac crest and the umbilicus. For AA males, minimal waist was significantly lower than the other 3 sites. A total of 13.8% of participants had ≥2 risk factors (19% of white males, 10% of AA males, 16.9% of white females, and 9.7% of AA females).

All WC measurement sites were highly correlated with one another within all race-by-sex groups (r = 0.97 to 0.99). Across the four WC sites, age-controlled correlations between WC and logVAT for the overall sample were between 0.81 and 0.83 (all $p<0.001$) and ranged from 0.81 and 0.89 (all $p<0.001$) for the race-by-sex groups (Table 3). Age-controlled correlations between each WC and cardiometabolic risk factors are also shown in Table 3. The correlations were almost identical across all anatomic sites for each risk factor. The prevalence of high WC ($\geq 90^{th}$ WC percentile for age and sex using the iliac crest site) differed across the WC measurement sites (Table 4). For males, the prevalence varied from 16.6% to 25.1%, and for females the percentage varied from 24.5% to 38.3%, depending on WC site.

Discussion

Waist circumference, along with BMI, is a primary tool for measuring adiposity in many settings (1). Due to the number of anatomic sites for WC measurement that are routinely used, there is a pressing need for studies that evaluate the different WC protocols in children against gold-standard measures (11). This is the first study to examine the association between multiple common waist circumference methodologies with total abdominal VAT in a biracial sample of children. We identified significant differences in absolute WC values across the four measurement sites in white and AA children. While differences in absolute WC between sites led to under- or over-estimation of the prevalence of abdominal obesity (Table 4), the correlations between WC measured at each site and VAT and with individual cardiometabolic risk factors were similar (Table 3).

Similar to other studies in children (3,10,11,13,14,16), we found differences in the absolute WC measurement between the largest and smallest WC measurement for each race-by-sex group (3.1–6.2 cm). Johnson *et al.* (2010) found differences of 11.3 cm between the largest and smallest site with narrowest waist being the smallest and umbilicus the largest in a sample of 73 overweight children aged 8–17 years (10). Wang and colleagues (2003) also reported differences of 1.5 cm in males and 4.5 cm in females between the largest and smallest sites and again the narrowest or minimal waist was significantly smaller than the other sites assessed (3).

Similar to other studies in adults (12,14) and children (16), Table 4 illustrates that using a different WC measurement site can impact the prevalence of high WC (26). The WC percentiles used were developed using the iliac crest (7) so it is reassuring to see that the midway, umbilicus and iliac sites all resulted in a similar prevalence, but the minimal WC resulted in a lower prevalence of abdominal obesity. Given the growing interest in WC as a marker of obesity-related health risks in children and adolescents, pediatric reference data have been developed for a number of countries including the U.S. (7), Canada (27), the United Kingdom (28), and Australia (29). However, comparisons across countries could be hampered due to the different measurement protocols employed. In the development of waist percentile scores and reference data in various countries, WC has been measured at the superior border of the iliac crest,(7,30) the narrowest waist (27,28), the umbilicus (29) and at the midpoint between the lowest rib and the iliac crest (31–36). If tracking children's growth over time, it would be prudent to be consistent in the use of one WC site.

All WC sites correlated similarly to VAT in each race-by-sex group. Bosy-Westphal *et al.* (2010) reported correlations between three WC sites and VAT of a similar magnitude to the present results (0.65–0.76 in prepubertal children and 0.82–0.87 in pubertal children) (14). However, the authors indicated differences in correlations in prepubertal boys: VAT and iliac crest (r = 0.65) was lower than VAT and the midway (r = 0.74) and distal border of the lowest rib (r = 0.76). Abdominal adiposity, in particular intra-abdominal VAT, is considered

to be the most dyslipidemic and atherogenic fat depot in the human body (37) and has been related to elevated triglycerides and fasting insulin and other risk factors in children (38). Given the expense and the expertise required to measure VAT by imaging techniques, finding an anthropometric assessment method which can identify at-risk children or those who require further clinical assessment is warranted. WC has explained a larger proportion of the variance in VAT in children than BMI (39) so much research has focused on developing WC protocols. Although WC was moderately correlated with VAT in the present study ($r = 0.81–0.89$) WC was more highly correlated with total abdominal adiposity and abdominal subcutaneous adiposity with correlations between 0.94 and 0.96 (results not reported).

WC has been linked to cardiometabolic health in children (40), so how each WC site relates to individual cardiometabolic risk factors is important. In one of the few studies which included children, Bosy-Westphal *et al.* (2010) reported that three WC sites had similar correlations with blood pressure, triglycerides and HDL-C (14). Conversely, Johnson *et al.* (2010) found the narrowest waist and midpoint provided the most consistent association with metabolic risk in a sample of overweight children (mean age 12.5 years) (10). We have reported that each WC site displayed similar relationships to all health variables and this is unsurprising due to the high correlations between sites that have been reported in adults (41) and in the present study.

Age, sex and ethnic-specific WC thresholds (measured at the midpoint) for predicting risk factor clustering (42) as well as age, sex and ethnic-specific WC percentiles (measured at the iliac crest) based on a representative sample of the US population (7) have been proposed for children. Differences in absolute WC measurement may affect how these WC values are interpreted. In a review, the sites of WC measurement did not affect the relationship between WC, morbidity and mortality in adults (41). This review also identified differences in the actual practical measurement procedures for the same site in adults (41). Pooling WC data from studies which have used different protocols may lead to differences in the prevalence of obesity or weaken the relationships between WC and risk factors or mortality (14). Because all WC sites correlated well with VAT in this study, choosing a WC site which is more acceptable to a pediatric population or easier to perform should be recommended. Bony landmarks are a useful structural guide to aid the measurement but these can be hard to identify in more overweight children and can lead to embarrassment (11). Conversely, the identification of two anatomical landmarks is time consuming and leaves more room for error (3) although the intra- and inter-observer technical errors of measurement did not differ across the four measurement sites in the present study.

The relatively large and racially diverse sample spanning a large age range is a marked strength of the present study. The use of MRI to quantify abdominal adiposity allowed for a robust analysis of the performance of each anatomical WC site. Inter and intra-tester reliability values were high for all sites and compared well with other studies (3). The present study used a cross-sectional design, and future studies should consider using a longitudinal design to identify the best WC thresholds for the prediction of cardiometabolic risk in these populations.

Conclusions

While a difference of 4.8 cm in the absolute measurements of WC at four commonly used anatomical locations affected obesity prevalence, the relationships with depot-specific adiposity and cardiometabolic risk factors were similar regardless of race or sex.

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PTK, AKG and STB conceived the study and acquired the data, and DMH, AES and PTK ran the analysis and interpreted the data. All authors were responsible for drafting and revising the paper and all had final approval of the submitted and published version. We acknowledge the efforts of Emily Mire for data management; Amber Dragg and the clinical staff for data collection; and the Pennington Biomedical Imaging Core for analysis of MRI and DXA data.

Abbreviations

WC	Waist circumference
VAT	Visceral adipose tissue
MRI	Magnetic resonance imaging
AA	African American
BMI	Body mass index
HDL-C	High density lipoprotein cholesterol

References

1. Cornier M-A, Després J-P, Davis N, et al. Assessing adiposity: a scientific statement from the American Heart Association. Circulation. 2011; 124:1996–2019. [PubMed: 21947291]
2. Horlick M, Hediger ML. Measurement matters. J Pediatr. 2010; 156:178–181. [PubMed: 20105636]
3. Wang J, Thornton JC, Bari S, et al. Comparisons of waist circumferences measured at 4 sites. Am J Clin Nutr. 2003; 77:379–384. [PubMed: 12540397]
4. National Institute of Health. The practical guide: Identification, evaluation, and treatment of overweight and obesity in adults. 2000.
5. August GP, Caprio S, Fennoy I, et al. Prevention and treatment of pediatric obesity: An Endocrine Society clinical practice guideline based on expert opinion. J Clin Endocr Metab. 2008; 93:4576–4599. [PubMed: 18782869]
6. Center for Disease Control and Prevention. National Health and Nutrition Examination Survey (NHANES) Anthropometry Procedures Manual. 2009. URL http://www.cdc.gov/nchs/data/nhanes/nhanes_09_10/BodyMeasures_09.pdf
7. Fernandez JR, Redden DT, Pietrobelli A, Allison DB. Waist circumference percentiles in nationaly representative samples of African-American, European-American, and Mexican-American children and adolescents. J Pediatr. 2004; 145:439–444. [PubMed: 15480363]
8. World Health Organization. WHO STEPwise approach to surveillance (STEPS): Guide to physical measurements. World Health Organization; 2008. URL http://www.who.int/chp/steps/Part3_Section3.pdf
9. Mason C, Katzmarzyk PT. Variability in waist circumference measurements according to anatomic measurement site. Obesity. 2009; 17:1789–1795. [PubMed: 19343017]
10. Johnson ST, Kuk JL, Mackenzie KA, Huang TTK, Rosychuk RJ, Ball GDC. Metabolic risk varies according to waist circumference measurement site in overweight boys and girls. J Pediatr. 2010; 156:247–252. e241. [PubMed: 19863969]
11. Rudolf MCJ, Walker J, Cole TJ. What is the best way to measure waist circumference? Int J Pediatr Obes. 2007; 2:58–61. [PubMed: 17763011]
12. Matsushita Y, Tomita K, Yokoyama T, Mizoue T. Optimal Waist Circumference Measurement Site for Assessing the Metabolic Syndrome. Diabetes Care. 2009; 32:e70. [PubMed: 19460906]

13. Andaki ACR, Tinoco ALA, Mendes EL, Andaki Júnior R, Hills AP, Amorim PRS. Different waist circumference measurements and prediction of cardiovascular risk factors and metabolic syndrome in children. Obes Res and Clin Pract. 2012; 6:149–157.
14. Bosy-Westphal A, Booke C-A, Blöcker T, et al. Measurement site for waist circumference affects its accuracy as an index of visceral and abdominal subcutaneous fat in a caucasian population. J Nutr. 2010; 140:954–961. [PubMed: 20335625]
15. Willis LH, Slentz CA, Houmard JA, et al. Minimal versus umbilical waist circumference measures as indicators of cardiovascular disease risk. Obesity. 2007; 15:753–759. [PubMed: 17372327]
16. Hitze B, Bosy-Westphal A, Bielfeldt F, Settler U, Mönig H, Müller MJ. Measurement of waist circumference at four different sites in children, adolescents, and young adults: Concordance and correlation with nutritional status as well as cardiometabolic risk factors. Obesity Facts. 2008; 1:243–249. [PubMed: 20054185]
17. Lee S, Kuk JL, Hannon TS, Arslanian SA. Race and gender differences in the relationships between anthropometrics and abdominal fat in youth. Obesity. 2008; 16:1066–1071. [PubMed: 18356853]
18. Meng X-I, Rosenthal R, Rubin DB. Comparing correlated correlation coefficients. Psychol Bull. 1992; 111:172–175.
19. Lohman, TG.; Roche, AF. Anthropometric standardization reference manual. Champaign, IL: Human Kinetics; 1988.
20. McCarthy H, Jarrett H, Crawley H. The development of waist circumference percentiles in British children aged 5.0–16.9 y. The development of waist circumference percentiles in British children aged 5.0–16.9 y. 2001; 55:902–907.
21. Brambilla P, Manzoni P, Sironi S, et al. Peripheral and abdominal adiposity in childhood obesity. Int J Obes. 1994; 18:795–800.
22. Lee S, Kim Y, Kuk JL, Boada FE, Arslanian S. Whole-body MRI and ethnic differences in adipose tissue and skeletal muscle distribution in overweight black and white adolescent boys. J Obesity. 2011; 2011 ID: 159373.
23. Benfield LL, Fox KR, Peters DM, et al. Magnetic resonance imaging of abdominal adiposity in a large cohort of British children. Int J Obes Relat Metab Disord. 2008; 32:91–99.
24. National Heart Blood and Lung Institute. Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents. USDHHS and NIH; 2011. URL http://www.nhlbi.nih.gov/guidelines/cvd_ped/peds_guidelines_sum.pdf
25. US Department of Health and Human Services. The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents. National Institutes of Health; 2005. URL http://www.nhlbi.nih.gov/health/prof/heart/hbp/hbp_ped.pdf
26. Zimmet P, Alberti G, Kaufman F, et al. The metabolic syndrome in children and adolescents. Lancet. 2007; 369:2059–2061. [PubMed: 17586288]
27. Katzmarzyk PT. Waist circumference percentiles for Canadian youth 11–18 y of age. Eur J Clin Nutr. 2004; 58:1011–1015. [PubMed: 15220942]
28. McCarthy HD, Jarrett KV, Crawley HF. The development of waist circumference percentiles in British children aged 5.0–16.9 y. Eur J Clin Nutr. 2001; 55:902–907. [PubMed: 11593353]
29. Eisenmann JC. Waist circumference percentiles for 7- to 15-year-old Australian children. Acta Paediatr. 2005; 94:1182–1185. [PubMed: 16203670]
30. Sardinha L, Santos R, Vale S, et al. Waist circumference percentiles for Portuguese children and adolescents aged 10 to 18 years. Eur J Pediatr. 2012; 171:499–505. [PubMed: 21979563]
31. Schwandt P, Kelishadi R, Haas G-M. First reference curves of waist circumference for German children in comparison to international values: the PEP Family Heart Study. World J Pediatr. 2008; 4:259–266. [PubMed: 19104889]
32. Nawarycz LO, Krzyżaniak A, Stawiñska-Witoszyñska B, et al. Percentile distributions of waist circumference for 7–19-year-old Polish children and adolescents. Obesity Reviews. 2010; 11:281–288. [PubMed: 20003070]
33. Liu A, Hills A, Hu X, et al. Waist circumference cut-off values for the prediction of cardiovascular risk factors clustering in Chinese school-aged children: a cross-sectional study. BMC Public Health. 2010; 10:82. [PubMed: 20170510]

34. Galcheva SV, Iotova VM, Yotov YT, Grozdeva KP, Stratev VK, Tzaneva VI. Waist circumference percentile curves for Bulgarian children and adolescents aged 6–18 years. Int J Pediatr Obes. 2009; 4:381–388. [PubMed: 19922055]
35. Hatipoglu N, Ozturk A, Mazicioglu M, Kurtoglu S, Seyhan S, Lokoglu F. Waist circumference percentiles for 7- to 17-year-old Turkish children and adolescents. Eur J Pediatr. 2008; 167:383–389. [PubMed: 17487506]
36. Sung RYT, Yu CCW, Choi KC, et al. Waist circumference and body mass index in Chinese children: Cutoff values for predicting cardiovascular risk factors. Int J Obes. 2006; 31:550–558.
37. Després J-P, Lemieux I. Abdominal obesity and metabolic syndrome. Nature. 2006; 444:881–887. [PubMed: 17167477]
38. Gower BA, Nagy TR, Goran MI. Visceral fat, insulin sensitivity, and lipids in prepubertal children. Diabetes. 1999; 48:1515–1521. [PubMed: 10426367]
39. Brambilla P, Bedogni G, Moreno LA, et al. Crossvalidation of anthropometry against magnetic resonance imaging for the assessment of visceral and subcutaneous adipose tissue in children. Int J Obes. 2006; 30:23–30.
40. Savva SC, Tornaritis M, Savva ME, et al. Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. Int J Obes Relat Metab Disord. 2000; 24:1453–1458. [PubMed: 11126342]
41. Ross R, Berentzen T, Bradshaw AJ, et al. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? Obesity Reviews. 2008; 9:312–325. [PubMed: 17956544]
42. Katzmarzyk P, Srinivasan S, Chen W, Malina R, Bouchard C, Berenson G. Body mass index, waist circumference, and clustering of cardiovascular disease risk factors in a biracial sample of children and adolescents. Pediatrics. 2004; 114:198–205.
43. Cole T, Bellizzi M, Flegal K, Dietz W. Establishing a Standard Definition for Child Overweight and Obesity Worldwide: International Survey. BMJ. 2000; 320:1240–1243. [PubMed: 10797032]
44. Barlow SE. Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: summary report. Pediatrics. 2007; 120:S164–S192. [PubMed: 18055651]

'What is already known about this subject'

- A number of anatomic sites are used for the measurement of waist circumference
- A number of studies have documented differences in the absolute values of waist circumference measurements across these common sites in adults
- It is unclear whether waist circumference measurement site alters the relationship with abdominal adiposity and cardiometabolic risk factors in children.

'What this study adds'

- The absolute values of waist circumference at four anatomic locations (minimal, midway, iliac, umbilicus) differed and this affected prevalence of high ($\geq 90^{th}$ percentile) waist circumference
- The relationships between waist circumference values at four anatomic locations and both depot-specific adiposity and cardiometabolic risk factors were similar across race and sex groups.

Table 1

Inter- and Intra-tester reliability (n=31) for each waist circumference measurement site.

	Inter			Intra		
	ICC	**95% CI (L)**	**95% CI (U)**	**ICC**	**95% CI (L)**	**95% CI (U)**
Minimal	0.995	0.990	0.998	0.986	0.971	0.993
Midway	0.991	0.981	0.996	0.983	0.966	0.992
Iliac	0.989	0.978	0.995	0.985	0.969	0.993
Umbilicus	0.999	0.997	0.999	0.994	0.988	0.997

ICC- Intra-class correlations, U-Upper 95% confidence interval, L-Lower 95% confidence interval

Table 2

Participant characteristics.

	White		African American		
	Males (n=95)	**Females (n=83)**	**Males (n=80)**	**Females (n=113)**	**All (n=371)**
Age					
5–9 years (%)	20.0	15.7	18.7	23.0	19.7
10–13 years (%)	41.1	49.4	48.8	43.4	45.3
14–18 years (%)	38.9	34.9	32.5	33.6	35.0
BMI z-score	0.74 (1.13)	0.74 (1.00)	0.97 (1.15)	1.20 (1.19)	0.93 (1.14)
Obese IOTF (%)	22.1	18.1	28.7	39.8	28.0
Obese CDC (%)	27.4	20.5	33.7	47.8	33.4
Waist Circumference (cm)					
Minimal	71.7 (14.4)	69.3 (12.3)	71.7 (16.2)	74.7 (15.8)	72.1 (14.9)
Midway	74.1 (16.7)	72.1 (13.9)	73.9 (18.8)[a]	77.7 (18.1)	74.7 (17.1)
Iliac	75.2 (17.4)[a]	74.4 (14.2)	74.6 (19.3)[a]	79.7 (18.8)[a]	76.3 (17.7)
Umbilicus	75.8 (17.2)[a]	75.5 (14.8)	74.9 (19.7)[a]	80.2 (19.4)[a]	76.9 (18.0)
VAT (liters)	0.18 (0.20)	0.16 (0.14)	0.12 (0.13)	0.14 (0.13)	0.15 (0.15)
% of participants with					
Hightriglycerides	33.7	41.0	11.3	14.2	24.5
Low HDL-C	36.8	24.1	23.8	15.9	24.8
High blood pressure	6.3	2.4	7.6	8.9	6.5
High fasting glucose	3.2	2.4	3.8	5.3	3.8
≥2 Risk factors	19.0	16.9	10.0	9.7	13.8

Note: Values are presented as means (SD).

[a]Same letter indicates no significant difference between WC measurement site within each race-by-sex group. Significant difference ($p<0.05$) unless indicated by the same letter. Obesity prevalence (%) are based on the International Obesity Taskforce(43)and the Center for Disease Control and Prevention(44)definitions. HDL-C- high density lipoprotein cholesterol.

Table 3

Age-controlled correlations between each waist circumference and visceral adiposity and cardiometabolic risk factors.

White Males	Minimal	Midway	Iliac	Umbilicus	AA Males	Minimal	Midway	Iliac	Umbilicus
logVAT	**0.85**	**0.85**	**0.85**	**0.86**	**logVAT**	**0.82**	**0.81**	**0.81**	**0.81**
TG	**0.41**	**0.41**	**0.41**	**0.42**	**TG**	**0.36**	**0.32**	**0.30**	**0.32**
HDL-C	**−0.26**	**−0.26**	**−0.27**	**−0.27**	**HDL-C**	**−0.27**	**−0.26**	**−0.25**	**−0.24**
Glu	0.06	0.10	0.11	0.09	**Glu**	0.22	**0.24**	**0.23**	**0.23**
SBP	**0.46**	**0.45**	**0.45**	**0.45**	**SBP**	**0.39**	**0.39**	**0.38**	**0.39**
DBP	0.18	0.19	0.19	0.20	**DBP**	**0.37**	**0.36**	**0.35**	**0.36**
White Females	**Minimal**	**Midway**	**Iliac**	**Umbilicus**	**AA Females**	**Minimal**	**Midway**	**Iliac**	**Umbilicus**
logVAT	**0.88**	**0.88**	**0.88**	**0.89**	**logVAT**	**0.87**	**0.87**	**0.86**	**0.87**
TG	**0.40**	**0.40**	**0.39**	**0.40**	**TG**	**0.29**	**0.29**	**0.29**	**0.30**
HDL-C	**−0.41**	**−0.40**	**−0.40**	**−0.41**	**HDL-C**	**−0.31**	**−0.31**	**−0.30**	**−0.34**
Glu	**0.30**	**0.29**	**0.31**	**0.28**	**Glu**	**0.20**	**0.19**	**0.19**	0.18
SBP	**0.51**	**0.51**	**0.52**	**0.50**	**SBP**	**0.30**	**0.29**	**0.28**	**0.27**
DBP	**0.44**	**0.46**	**0.47**	**0.44**	**DBP**	**0.25**	**0.26**	**0.27**	**0.26**

Note: All **bolded** correlations are significant (p<.05). logVAT- log transformed visceral adipose tissue; AA- African American; TG- triglycerides; HDL-C- high density lipoprotein cholesterol; GLU- glucose; SBP- systolic blood pressure; DBP- diastolic blood pressure.

Table 4

Percentage of participants ≥90th WC percentile (7) using each of the four waist circumference measurements.

Site	Males (n=175)	Females (n=296)	All (n=371)
Minimal	16.6	24.5	20.7
Midway	24.0	34.7	29.6
Iliac	25.1	37.2	31.5
Umbilicus	25.1	38.3	31.1

Note: The WC percentiles were developed for age and sex using the iliac crest site(7)