Metabolic Risk Varies According to Waist Circumference Measurement Site in Overweight Boys and Girls

Steven T. Johnson, PhD, Jennifer L. Kuk, PhD, Kelly A. Mackenzie, MSc, Terry T-K. Huang, PhD, MPH, Rhonda J. Rosychuk, PhD, and Geoff D. C. Ball, PhD, RD

Objectives To compare waist circumference (WC) values measured at 4 commonly recommended sites and examine the relationships between WC sites and markers of metabolic risk in a sample of overweight boys and girls referred for weight management.

Study design Overweight (mean body mass index percentile, 98.7; SD, 1.0) children and adolescents (n = 73; 41 girls, 32 boys; mean age, 12.5 years; SD, 2.6 years) had WC measured at 4 sites: iliac crest (WC1), narrowest waist (WC2), midpoint between the floating rib and iliac crest (WC3), and umbilicus (WC4). Height, weight, fasting insulin level, glucose level, cholesterol level, and systolic and diastolic blood pressure were also measured.

Results Overall, WC1 (108.5 cm; SD, 16.3 cm) was greater than WC2 (97.4 cm; SD, 13.6 cm; $P < .003$), and WC2 was smaller than WC3 (104.3 cm; SD, 15.3 cm; $P = .02$) and WC4 (108.7 cm; SD, 16.2 cm; $P < .0003$). With logistic regression, WC2 and WC3 were revealed to be more consistently associated with metabolic syndrome by using 3 different definitions.

Conclusion In our sample, we observed differences in 4 commonly recommended WC measurement sites and found that all sites were not equivalently associated with metabolic risk. Our findings provide preliminary support suggesting that WC measured at the narrowest waist and midpoint between the floating rib and iliac crest may represent the measurement sites most closely associated with metabolic risk in overweight boys and girls. *(J Pediatr 2010;156:247-52)*.

See editorial, p 178

Pediatric obesity has become increasingly common in recent decades.[1-3] Although most reports are based on body mass index (BMI) data, waist circumference (WC) measurements have yielded important insight as well. For example, abdominal fat appears to have increased to a greater degree than total body fat in children and adolescents in the past 10 years.[4,5] From a health perspective, these observations are cause for concern because numerous studies have demonstrated that abdominal obesity is strongly associated with metabolic risk.

A high level of abdominal fat in childhood is linked to insulin resistance, dyslipidemia, and high blood pressure,[6-8] all key features of the metabolic syndrome (MetS). A number of cross-sectional studies have demonstrated that WC is strongly related to risk factors for type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD).[9-11] Because adiposity and metabolic risk factors are likely to track from childhood to adulthood,[12-15] especially at very high levels of body fat, children and adolescents with a high WC are at increased risk for developing T2DM and CVD early in life. These findings provide strong justification for including a WC measurement as part of regular pediatric health assessments[16,17] to track changes with time and to gauge whether weight management strategies have a positive influence on abdominal fat.

Currently, there is no consensus on an evidence-based WC measurement protocol for children and adolescents, an issue which has implications for both research and clinical care. WC sites commonly described in the pediatric literature include the top of the iliac crest,[4,16,18] midpoint between the iliac crest and floating rib,[5,9,13,19] and the level of the umbilicus.[12,17,20] The objectives of this study were to determine the relationships among these 4 commonly measured WC sites

BMI	Body mass index	NCEP	National Cholesterol Education Program
CVD	Cardiovascular disease		
DBP	Diastolic blood pressure	NHANES	National Health and Nutrition Examination Survey
HOMA-IR	Homeostatic model assessment-insulin resistance	OR	Odds ratio
HDL	High density lipoprotein	PCWH	Pediatric Centre for Weight and Health
IDF	International diabetes federation		
LDL	Low density lipoprotein	SBP	Systolic blood pressure
MetS	Metabolic syndrome	T2DM	Type 2 diabetes mellitus
		WC	Wasist circumference

From the School of Public Health, University of Alberta, Edmonton, Alberta, Canada (S.J.); Department of Pediatrics, University of Alberta, Edmonton, Alberta, Canada (R.R., G.B.); School of Kinesiology and Health Science, York University, Toronto, Ontario, Canada (J.K.); Pediatric Centre for Weight and Health, Stollery Children's Hospital, Edmonton, Alberta, Canada (K.M., G.B.); and Obesity Research Strategic Core, Eunice Kennedy Shriver National Institute of Child Health and Human Development, Bethesda, MD (T.H.)

Supported by a Research Trainee Grant (awarded to Dr Johnson) from the Department of Pediatrics, University of Alberta, Edmonton, Alberta, Canada. Dr Rosychuk is supported by a Population Health Investigator (PHI) Award from the Alberta Heritage Foundation for Medical Research (AHFMR). Dr Ball is supported by a PHI from AHFMR and a New Investigator Award from the Canadian Institutes of Health Research. Contents of this paper do not necessarily represent the views or policies of the US National Institutes of Health. The authors declare no conflicts of interest.

 10.1016/j.jpeds.2009.08.010

and body mass index (BMI) z-score and to determine which sites were most strongly associated with metabolic risk in a sample of overweight boys and girls.

Methods

This study included 8- to 17-year-old children and adolescents with an age- and sex-specific BMI ≥85th percentile.[21] All participants were generally healthy outpatients who were referred by physicians to the Pediatric Centre for Weight and Health (PCWH) at the Stollery Children's Hospital (Edmonton, Alberta, Canada). The PCWH is a research-based, clinical weight management center that is part of Alberta Health Service's Weight Wise initiative (www.capitalhealth.ca/weightwise). This study received ethical approval from the Health Research Ethics Board at the University of Alberta.

All WC measurements were taken by 1 clinician using a spring-loaded Gulick anthropometric tape (FitSystems, Calgary, Alberta, Canada). With the subject standing in front of a mirror, each measurement was performed with the tape snugly positioned on, but not compressing, the skin. The tape was pulled until calibration tension was achieved. When performing measurements, the clinician was positioned so she could view the opposite side of the tape to ensure it was parallel against the skin. Clothing was positioned so the abdomen was exposed (bottom of t-shirt was positioned below the arms, which were crossed over the chest; pants/shorts were loosened and lowered slightly to reveal the hips). Recordings were taken at the end of a normal expiration and not during breath holding or abdominal muscle contractions. Consistent with our clinical protocol, all 4 sites (WC1, iliac crest; WC2, narrowest waist between the xyphoid process and iliac crest; WC3, midpoint between the floating rib and iliac crest; WC4, level of umbilicus) were measured sequentially. This procedure was repeated, and when the first and second values for each individual site differed >0.5 cm, a third measurement was taken in the same sequential order. The divergent measure (eg, ≥0.5 cm) was not included when calculating the average value. All values were recorded to the nearest 0.1 cm. WC values were converted to age- and sex-specific WC z-scores by using published results from a Canadian representative sample.[22]

The same clinician performed all anthropometric measurements as well. Height was measured without shoes to the nearest 0.1 cm with a wall-mounted electronic stadiometer (SECA 242 stadiometer, Hanover, Maryland), and weight was assessed to the nearest 0.1 kg with a digital medical scale (SECA 644, Hanover, Maryland). Height and weight values were then entered into EpiInfo (Centers for Disease Control and Prevention, Atlanta, Georgia) to calculate BMI, age- and sex-specific BMI percentile, and BMI z-score. We included BMI z-score in several analyses as a proxy measure of age- and sex-adjusted total body fat.

After a 12-hour fast, a single blood sample was collected at the University of Alberta Hospital outpatient laboratory. The following variables were measured: total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol, triglycerides, plasma glucose, and insulin levels. Glucose level was analyzed with a Beckman LX20 analyzer, and all other variables were measured with electrochemiluminescence (Elecsys 2010, Roche, Basel, Switzerland).

While seated and after a 5-minute rest, systolic and diastolic blood pressures (SBP and DBP) were measured manually by the same clinician using a sphygmomanometer and an appropriately-sized arm cuff, according to established Canadian guidelines.[23] A second measure was taken 5 minutes later; when a difference ≥10 mm Hg in SBP was observed, the lower of the 2 values was recorded.

Despite a high level of relevance for clinicians and researchers, a universal definition of MetS is not established.[24] For the purpose of this study, MetS was classified with 3 separate and common definitions, including that of the International Diabetes Federation (IDF),[25] Cook et al,[26] and modified National Cholesterol Education Program (NCEP) criteria.[27] The IDF[25] defines MetS as the presence of central obesity (<16 years of age: WC >90th age- and sex-specific percentile; National Health and Nutrition Examination Survey [NHANES] III; or ≥16 years of age: >94 cm for male and >80 for female patients) with ≥2 of these factors: 1) SBP >130 mm Hg or DBP >85 mm Hg; 2) fasting glucose level >5.6 mM; 3) HDL cholesterol level <1.03 mM; and 4) triglycerides level >1.7 mM. Cook et al[26] defined MetS as >3 of these factors: 1) WC ≥90th age- and sex-specific percentile (NHANES III); 2) SBP or DBP ≥90th age-, sex-, and height-specific percentile; 3) fasting glucose level ≥6.1 mM; 4) HDL cholesterol level ≤1.03 mM; and 5) triglycerides level ≥1.24 mM. The modified NCEP[24] definition of MetS includes ≥3 of these factors: 1) WC ≥90th age- and sex-specific percentile (NHANES III); 2) SBP >130 mm Hg or DBP >85 mm Hg; 3) fasting glucose level >5.6 mM; 4) HDL cholesterol level <1.04 mM (for boys) or HDL cholesterol level <1.29 mM (for girls); and 5) triglycerides level >1.69 mM.

In addition to the MetS definitions, we calculated an overall metabolic risk score (maximum = 7) as the total number of MetS features (excluding WC); the metabolic risk score included the aforementioned features plus LDL cholesterol level (>4.1 mM), total cholesterol level (>5.2 mM), and insulin resistance (homeostatic model assessment [HOMA] >2.5). HOMA was calculated with the formula: fasting insulin (mU/L) × fasting glucose (mM) / 22.5.[26]

With univariate analyses, all continuous variables were shown to be normally distributed. Independent sample *t* tests and χ^2 tests were used to test for differences between boys and girls. Relationships between each of the 4 different WC sites and BMI z-score were assessed with Pearson correlations. Differences across the 4 WC sites and the relationship between BMI z-score and WC at the 4 sites were assessed by using repeated measures analyses (Proc Mixed). Partial correlations were used to examine the strength of the associations among the metabolic risk factors, WC, and BMI, with control for age, sex, and ethnicity.

Logistic regression was used to calculate the odds of MetS and increasing number of metabolic syndrome risk factors

across WC and BMI z-score. To avoid confounding, the MetS in these models excluded WC, with MetS defined by using 3 of the 4 remaining criteria for Cook et al and NCEP and 2 of the remaining 4 criteria for IDF. To facilitate the comparison of odds ratios (ORs) in the different variables, figures with ORs were expressed per SD unit. All models were undisturbed by multi-collinearity with tolerance ≤0.20 and variance inflation factor ≤5.[28] For all regression analyses, sex interaction terms were examined. When the interaction terms were significant, further analyses were conducted within each sex separately.[29] All analyses were further adjusted for age (as a continuous variable) and ethnicity (as a dichotomous variable: non-white = 0; white = 1). All statistical analyses were performed with SAS software version 9.1 (SAS Institute Inc., Cary, North Carolina), with statistical significance set at $P < .05$.

Results

Demographic and anthropometric characteristics of the 73 boys and girls included in this study are shown in Table I. Boys tended to have higher BMI z-scores and percentiles than girls. All participants had a BMI >94th percentile, and 70 of 73 participants (95.9%) were consistently classified as abdominally obese (>90th age- and sex percentile, NHANES III). Of the 3 individuals who were not consistently defined as abdominally obese, 1 girl was identified as not abdominally obese by using all 4 WC sites, 1 girl was deemed abdominally obese by using 2 of the 4 sites, and 1 boy was considered abdominally obese by using 3 of the 4 measurement sites. The prevalence of the MetS was unchanged by the WC measurement site used.

For boys, the narrowest site (WC2) was significantly smaller than the iliac crest (WC1; 9.3 cm, $P = .01$) and umbilicus (WC4; 9.5 cm, $P = .008$), but not different from the midpoint between the floating rib and iliac crest (WC3; 6.8 cm, $P > 0.10$; Figure 1; available at www.jpeds.com). For girls, WC2 was smaller than WC1, WC3, and WC4 (12.5 cm, $P < .0003$; 7.0 cm, $P = .02$; and 12.5 cm, $P < .0003$, respectively), which were not different from each other ($P > .05$; Figure 1). No evidence of statistically significant differences by sex within each WC category were found ($P = .88$ interaction effect). The metabolic characteristics of the participants are shown in Table II. WC measurements at all 4 sites were highly correlated with one another (r = 0.93-1.00; $P < .0001$), but were more moderately related to BMI z-score (r = 0.58-0.70; $P < .0001$; Table III; available at www.jpeds.com). High LDL cholesterol and low HDL cholesterol levels were more prevalent in girls ($P = .045$ and $P = .02$, respectively).

The associations between WC z-score, BMI z-score, and metabolic risk are shown in Table IV (available at www.jpeds.com), controlling statistically for age, sex, and ethnicity. SPB and DBP, fasting insulin, and HOMA-IR were all positively correlated with WC and BMI z-score regardless of measurement site. However, triglycerides level was positively correlated only with WC2 and WC3. In general, the WC sites and BMI z-score were comparable in their association with metabolic risk, with WC2 and WC3 being slightly stronger correlates (Table IV).

Table I. Demographic and anthropometric characteristics

	Boys (n = 32)	Girls (n = 41)	Total (n = 73)	*P* value
Ethnicity, % white (n)	78.1 (25)	85.4 (35)	82.2 (60)	-
Age (years)	12.1 (2.6)	12.7 (2.6)	12.5 (2.6)	.31
Height (cm)	156.0 (14.2)	158.3 (10.9)	157.3 (12.4)	.45
Weight (kg)	82.2 (27.7)	85.1 (23.0)	83.8 (25.1)	.63
BMI (kg/m^2)	32.8 (6.5)	33.4 (6.3)	33.2 (6.3)	.23
BMI z-score	2.4 (0.3)	2.3 (0.3)	2.3 (0.3)	.05
BMI percentile (%)	99.0 (0.7)	98.5 (1.1)	98.7 (1.0)	.04

Values are presented as means (SD).

The proportions of boys and girls with MetS varied slightly according to the classification system (IDF, 47%; Cook et al, 47%; NCEP, 37%). The associations between WC, BMI z-score, and MetS applying the 3 MetS definitions are shown in Figure 2. There was no evidence of significant sex × waist or sex × BMI interactions ($P = .11$-$.71$). Although the pattern of association among WC, BMI z-score, and MetS was similar across the definitions, the significance of the individual associations varied slightly according to WC measurement site. WC2 (OR, 2.18; 95% CI, 1.23-3.85; $P = .007$), WC3 (OR, 1.81; 95% CI, 1.06-3.09; $P = .03$), and BMI z-score (OR, 2.11; 95% CI, 1.22-3.66; $P = .007$) were associated with an increased risk of MetS as defined with IDF (Figure 2, A) and the number of IDF MetS criteria (Figure 2, B). According to the definition by Cook et al, MetS was not associated with BMI or WC at any site, but WC2 (OR, 2.10; 95% CI, 1.28-3.44; $P = .003$), WC3 (OR, 1.83, 95% CI, 1.13-2.98; $P = .01$), and BMI z-score (OR, 1.94; 95% CI, 1.19-3.16; $P = .008$) were associated with the number of MetS risk factors. For the NCEP definition, WC2 (OR, 3.80; 95% CI, 1.28-11.36; $P = .02$) and WC3 (OR, 3.24; 95% CI, 1.08-9.72; $P = .04$), but not WC1 and WC4, were associated with MetS. BMI z-score and all 4 WC sites were positively associated with the number of MetS risk factors according to the NCEP MetS definition.

Discussion

The lack of a standardized, evidence-based protocol for measuring WC in children and adolescents represents a critical knowledge gap in the obesity literature. To date, no pediatric study has examined potential differences across commonly measured WC sites and determined whether the relationship between WC and metabolic risk differs according to measurement site. In this study, we found that differences existed in the 4 WC measurement sites (for boys, WC1 and WC4 < WC2; for girls, WC1, WC3, and WC4 < WC2) and that all sites were not significantly or equivalently associated with metabolic risk. Overall, waist circumferences measured at the narrowest site (WC2) and at the midpoint between floating rib and iliac crest (WC3) were most strongly and

Table II. Comparison of metabolic risk across boys and girls

	Risk factor, mean (SD)		Prevalence (%)	
	Boys (n = 32)	Girls (n = 41)	Boys (n = 32)	Girls (n = 41)
SBP (mm Hg)	110.9 (14.4)	109.2 (9.7)	12.5	4.9
DBP (mm Hg)	70.7 (9.7)	69.9 (9.4)	12.5	4.9
Triglycerides (mM)	1.6 (0.7)	1.5 (0.8)	37.5	31.7
Total cholesterol (mM)	4.6 (1.2)	4.2 (0.9)	12.5	14.6
LDL cholesterol (mM)	2.9 (1.2)	2.6 (0.8)	9.4	0.0*
HDL cholesterol (mM)	1.0 (0.2)	0.9 (0.2)	75.0	95.1*
HOMA-IR	5.5 (2.7)	5.6 (4.5)	84.4	80.5
Insulin (mU/L)	25.0 (12.8)	25.5 (18.3)	NA	NA
Glucose (mM)	5.0 (0.4)	4.8 (0.5)	3.1	7.3
MetS†				
NCEP	NA	NA	34.4	39.0
IDF	NA	NA	50.0	43.9
Cook	NA	NA	56.8	39.0

*Significant sex difference ($P < .05$).
†Metabolic syndrome was defined by using the IDF,[25] Cook,[26] and NCEP[27] diagnostic criteria (see Methods section for full details). Waist circumference was included in the definition for prevalence estimates.

consistently associated with the MetS and the number of metabolic risk factors.

Although several studies have compared different WC sites in adults (eg, Willis et al, Bigaard et al, and Want et al[30-32]), the pediatric literature is limited. Rudolf et al[33] included an examination of measurement consistency across 3 WC sites (the midpoint between the bony markers of the ribs and superior iliac crest, the level of the lateral crease that appears when leaning to 1 side, and 4 cm above the umbilicus). The authors found little variability across the sites measured in their sample (n = 41) of non-overweight, overweight, and obese children. Overall, the authors recommended using the site 4 cm above the umbilicus because of measurement ease and participant preference; data on metabolic risk and body composition were not reported. Groeneveld et al[34] reported data on the basis of WC measurements from 2 WC sites (umbilical and narrowest waist [referred to as natural waist]) in a group of 583 Guatemalan children. The authors described and compared these 2 WC sites across socioeconomic status and sex groupings; their objective was not to determine whether 1 site was superior to the other, but to simply explore relationships between these sites and BMI and waist-to-height ratio. Our study adds new evidence for a preferred WC measurement site and suggests differences between male and female participants may not be easily discerned, a finding which may be due to anthropometric homogeneity in this sample of exclusively overweight boys and girls.

We found, as have other authors,[30] that the absolute difference in measurements at different WC sites can be detected in subjects who are overweight or obese. From a clinical standpoint, this can be problematic when WC is used for decision-making, performing comparisons between studies that included different measurement protocols, or interpreting the impact of weight management interventions on abdominal fat, because the magnitude of the change may vary as a function of the WC site. In their recent systematic review, Ross et al[35] concluded that although measurement variability and WC protocol varied across studies, the relationships among WC and all-cause and CVD mortality, cardiovascular disease, and T2DM remain relatively consistent. In the absence of similar disease end-points in our pediatric population, risk factors for T2DM and CVD provide a proximal frame of reference. We found that WC2 and WC3 were most strongly associated with metabolic risk; of all 4 WC sites included in this study, WC2 and WC3 were also the sites that were significantly associated (although modestly) with serum triglycerides levels (an important risk factor for CVD).

We agree with other authors[32,33] that the choice of WC measurement site should also consider practical issues, which may be particularly relevant for overweight and obese boys and girls, because measurement variability can increase at high levels of body fat.[32] The umbilicus is the easiest site to locate, but as a soft tissue landmark, has the potential to vary in time with growth and weight gain or loss. WC sites based on bony landmarks (ie, iliac crest and floating rib) require the anthropometrist to palpate the abdomen. Although these landmarks offer a consistent reference point and are recommended for adults,[33] the palpation may be uncomfortable for children and clinicians (especially for less-experienced individuals), and depending on the volume and distribution of abdominal fat, can be difficult to locate consistently. Undergoing repeated WC measurements that require palpation can also be a sensitive issue for overweight and obese boys and girls, especially for those who are self-conscious about their weight and shape. Measuring WC at the narrowest waist is advantageous because palpation is not required and the site can be landmarked with a brief visual inspection. In addition, this site is located slightly higher on the torso and tends to avoid skinfolds in individuals with higher levels of abdominal fat.

Despite a number of strengths, our study has some limitations. First, our convenience sample of boys and girls referred for weight management did not include any non-overweight participants; further, the number of non-Caucasian children and adolescents was small. For these reasons, potential WC site differences and relationships between WC sites and metabolic risk factors across a broader range of weight categories (ie, underweight, normal weight, overweight, obese) and ethnicities (ie, First Nations, South Asian, Latino, African-American) remain to be determined. Second, adult studies have shown that WC measured at the narrowest waist (WC2 in our study) was a strong predictor of total adipose tissue and visceral adipose tissue measured with computed tomography.[34,35] Our analyses focused on metabolic risk and not body fat distribution per se, but research is needed to identify which WC site is most strongly related to total visceral adipose tissue and subcutaneous abdominal adipose tissue in children and adolescents, because both fat depots are strongly associated with metabolic risk.[36-39] Our clinical protocol included measuring the 4 WC sites in sequential order. Although unlikely to have a substantial influence on our

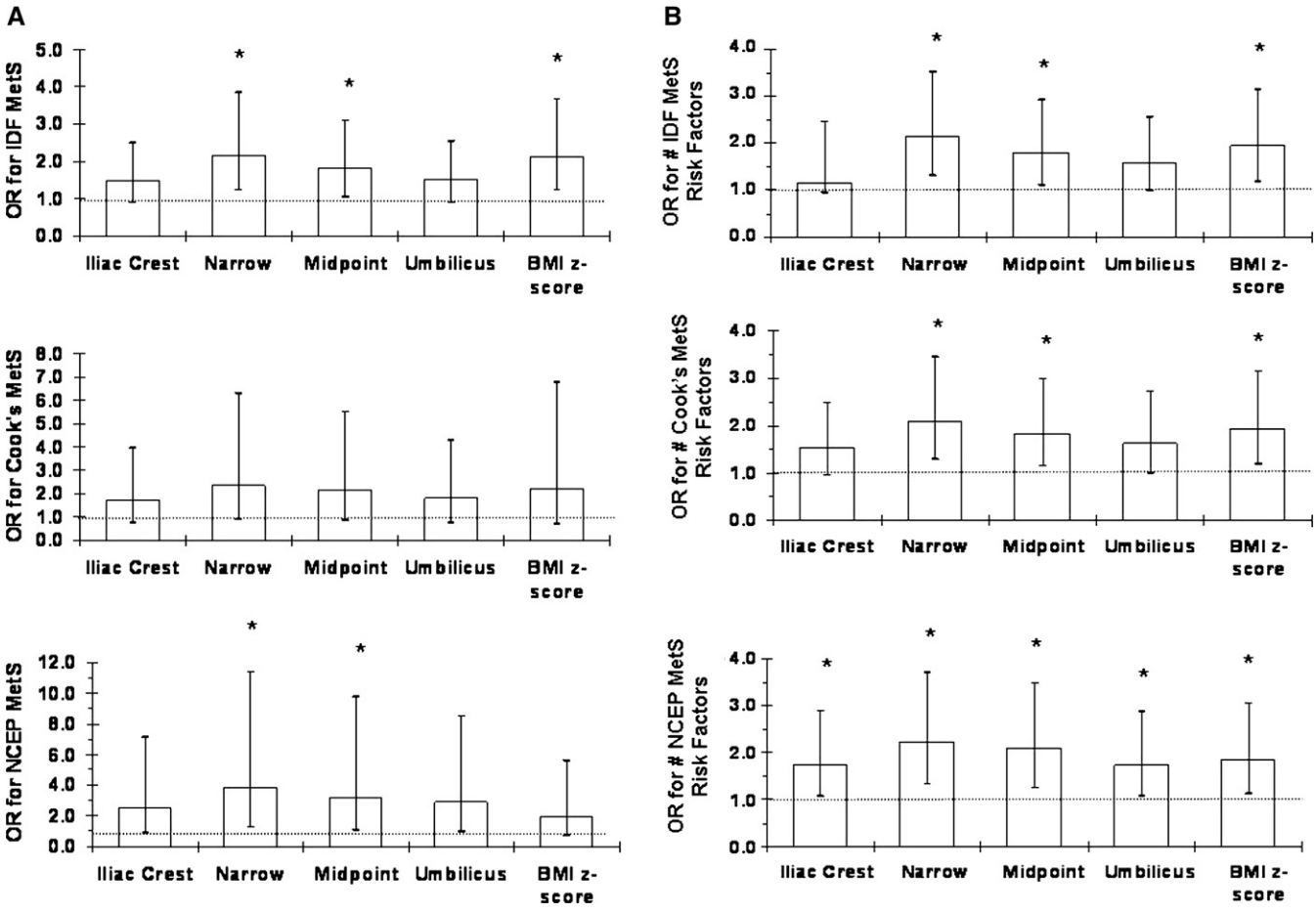

Figure 2. **A,** Association between waist circumference and BMI z-score with the metabolic syndrome by using different definitions. **B,** Association between waist circumference and BMI z-score with the number of metabolic risk factors.*$P < .05$; Iliac crest (WC1), narrowest waist (WC2), midpoint between floating rib and iliac crest (WC3) and umbilicus (WC4). MetS was defined according to the IDF[25] as the presence of central obesity (<16 years of age: WC >90th age- and sex-specific percentile [NHANES III]; or 16+ years of age: >94 cm for male and >80 for female participants) in conjunction with any 2 or more of the 4 other risk factors: SBP >130 or DBP >85 mm Hg; fasting glucose level >5.6 mM; HDL <1.03 mM; and triglycerides >1.7 mM. According to Cook's criteria,[26] MetS requires the presence of >3 of the following factors: WC ≥90th age- and sex-specific percentile (NHANES III); BP ≥90th age-, sex-, and height-specific percentile; fasting glucose level ≥6.1 mM; HDL cholesterol level ≤1.03 mM; and triglycerides level ≥1.24 mM. The NCEP[27] defines MetS as the presence of ≥3 of these factors: 1) WC ≥90th age- and sex-specific percentile (NHANES III); 2) SBP >130 mm Hg or DBP >85 mm Hg; 3) fasting glucose >5.6 mM; 4) HDL cholesterol level <1.04 mM (for boys) or HDL cholesterol level <1.29 mM (for girls); and 5) triglycerides level >1.69 mM. ORs are expressed per SD unit of BMI and waist circumference z-scores. All models were adjusted for age, sex, and ethnicity.

findings, our scientific rigor would have been enhanced if the 4 WC sites had been measured in random order. Finally, our analyses were based on cross-sectional data. It is unknown whether different WC sites would be most sensitive to changes in abdominal body fat distribution and risk factors for T2DM and CVD. In this regard, taking WC measurements at different sites in the context of a longitudinal cohort study or weight management intervention would provide important insight on the patterns of change with time.

We found that waist circumferences measured at the narrowest waist (WC2) and the midpoint between the floating rib and iliac crest (WC3) were the strongest predictors of metabolic risk in this sample of overweight boys and girls. The choice of WC measurement site should consider both objective data and technical issues of clinical relevance. Our findings should be used as a platform on which to build a stronger evidence base in this area. Additional research is needed to determine which WC sites represent preferred, evidence-based sites in other populations and in the context of longitudinal and interventional study designs. ■

The authors would like to thank all of the participating boys and girls who made this study possible.

Submitted for publication Apr 15, 2009; last revision received Jun 24, 2009; accepted Aug 12, 2009.

Reprint requests: Geoff D. C. Ball, PhD, RD, Assistant Professor, Department of Pediatrics, University of Alberta, Room 8228, Aberhart Centre, 11402 University Ave, Edmonton, AB, T6G 2R7, Canada. E-mail: geoff.ball@ualberta.ca.

References

1. Lobstein T, Jackson-Leach R. Child overweight and obesity in the USA: prevalence rates according to IOTF definitions. Int J Pediatr Obes 2007; 2:62-4.
2. Shields M. Overweight and obesity among children and youth. Health Rep 2006;17:27-42.
3. Dietz WH. Overweight in childhood and adolescence. N Engl J Med 2004;350:2414-6.
4. Garnett SP, Cowell CT, Baur LA, Shrewsbury VA, Chan A, Crawford D, et al. Increasing central adiposity: the Nepean longitudinal study of young people aged 7-8 to 12-13 y. Int J Obes 2005;29:1353-60.
5. McCarthy HD, Jarrett KV, Emmett PM, Rogers I. Trends in waist circumferences in young British children: a comparative study. Int J Obes 2005;29:157-62.
6. Freedman DS, Serdula MK, Srinivasan SR, Berenson GS. Relation of circumferences and skinfold thicknesses to lipid and insulin concentrations in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr 1999;69:308-17.
7. Goran MI, Gower BA. Relation between visceral fat and disease risk in children and adolescents. Am J Clin Nutr 1999;70:149-56S.
8. Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: importance of the intraabdominal fat depot. Am J Clin Nutr 1996;64:12-7.
9. Lee S, Bacha F, Gungor N, Arslanian SA. Waist circumference is an independent predictor of insulin resistance in black and white youths. J Pediatr 2006;148:188-94.
10. Moreno LA, Pineda I, Rodriguez G, Fleta J, Sarria A, Bueno M. Waist circumference for the screening of the metabolic syndrome in children. Acta Paediatr 2002;91:1307-12.
11. Savva SC, Tornaritis M, Savva ME, Kourides Y, Panagi A, Silikiotou N, 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;24:1453-8.
12. Srinivasan SR, Myers L, Berenson GS. Changes in metabolic syndrome variables since childhood in prehypertensive and hypertensive subjects: the Bogalusa Heart Study. Hypertension 2006;48:33-9.
13. Janssen I, Katzmarzyk PT, Srinivasan SR, Chen W, Malina RM, Bouchard C, et al. Combined influence of body mass index and waist circumference on coronary artery disease risk factors among children and adolescents. Pediatrics 2005;115:1623-30.
14. Nicklas TA, von Duvillard SP, Berenson GS. Tracking of serum lipids and lipoproteins from childhood to dyslipidemia in adults: the Bogalusa Heart Study. Int J Sports Med 2002;23:S39-43.
15. Srinivasan SR, Myers L, Berenson GS. Temporal association between obesity and hyperinsulinemia in children, adolescents, and young adults: the Bogalusa Heart Study. Metabolism 1999;48:928-34.
16. Esmaillzadeh A, Mirmiran P, Azizi F. Clustering of metabolic abnormalities in adolescents with the hypertriglyceridemic waist phenotype. Am J Clin Nutr 2006;83:36-46.
17. Hirschler V, Aranda C, Calcagno Mde L, Maccalini G, Jadzinsky M. Can waist circumference identify children with the metabolic syndrome? Arch Pediatr Adolesc Med 2005;159:740-4.
18. Higgins PB, Gower BA, Hunter GR, Goran MI. Defining health-related obesity in prepubertal children. Obes Res 2001;9:233-40.
19. Klasson-Heggebø L, Andersen LB, Wennlöf AH, Sardinha LB, Harro M, Froberg K, et al. Graded associations between cardiorespiratory fitness, fatness, and blood pressure in children and adolescents. Br J Sports Med 2006;40:25-9.
20. Ball GDC, Huang TT-K, Shaibi GQ, Weigensberg MJ, Cruz ML, Goran MI. Predicting visceral and subcutaneous abdominal adipose tissue in overweight Hispanic children. Int J Pediatr Obes 2006;1: 210-6.
21. Centers for Disease Control and Prevention. CDC Growth Charts. Department of Health and Human Services, National Center for Health Statistics. Atlanta: CDC;2000.
22. Katzmarzyk PT, Perusse L, Rao DC, Bouchard C. Familial risk of obesity and central adipose tissue distribution in the general Canadian population. Am J Epidemiol 1999;149:933-42.
23. Canadian Society for Exercise Physiology. The Canadian Physical Activity, Fitness & Lifestyle Approach (CPAFLA): CSEP-Health & Fitness Program's health-related appraisal and counselling strategy. 3rd ed. Ottawa, ON 2003.
24. Huang TTK. Finding thresholds of risk for components of the pediatric metabolic syndrome. J Pediatr 2008;152:158-9.
25. Zimmet P, Alberti KG, Kaufman F, Tajima N, Silink M, Arslanian S, et al. The metabolic syndrome in children and adolescents—an IDF consensus report. Pediatr Diabetes 2007;8:299-306.
26. 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;157:821-7.
27. Executive Summary of the Third Report of The National Cholesterol Education Program (NCEP) Expert Panel on Detection. Evaluation, And Treatment of High Blood Cholesterol In Adults (Adult Treatment Panel III). JAMA 2001;285:2486-97.
28. Stevens J. Intermediate statistics: a modern approach. 2nd ed. Mahwah, NJ: Lawrence Erlbaum Associates; 1999.
29. Matthews DR, Hosker JP, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 1985;28:412-9.
30. Willis LH, Slentz CA, Houmard JA, Johnson JL, Duscha BD, Aiken LB, et al. Minimal versus umbilical waist circumference measures as indicators of cardiovascular disease risk. Obesity 2007;15:753-9.
31. Bigaard J, Spanggaard I, Thomsen BL, Overvad K, Tjonneland A. Self-reported and technician-measured waist circumferences differ in middle-aged men and women. J Nutr 2005;135:2263-70.
32. Wang J, Thornton JC, Bari S, Williamson B, Gallagher D, Heymsfield SB, et al. Comparisons of waist circumferences measured at 4 sites. Am J Clin Nutr 2003;77:379-84.
33. Rudolf MC, Walker J, Cole TJ. What is the best way to measure waist circumference? Int J Pediatr Obes 2007;2:58-61.
34. Groeneveld IF, Solomons NW, Doak CM. Determination of central body fat by measuring natural waist and umbilical abdominal circumference in Guatemalan schoolchildren. Int J Pediatr Obes 2007;2: 114-21.
35. Ross R, Berentzen T, Bradshaw AJ, Janssen I, Kahn HS, Katzmarzyk PT, et al. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? Obes Rev 2008;9:312-25.
36. Clasey JL, Bouchard C, Teates CD, Riblett JE, Thorner MO, Hartman ML, et al. The use of anthropometric and dual energy X-ray absorptiometry (DXA) measures to estimate abdominal visceral fat in men and women. Obes Res 1999;7:256-64.
37. Lean MEJ, Han TS, Morrison CE. Waist circumference as a measure for indicating need for weight management. BMJ 1995;311:158-61.
38. Kim JA, Park HS. Association of abdominal fat distribution and cardiometabolic risk factors among obese Korean adolescents. Diabetes Metabol 2008;34:126-30.
39. Cruz ML, Bergman RN, Goran MI. Unique effect of visceral fat on insulin sensitivity in obese Hispanic children with a family history of type 2 diabetes. Diabetes Care 2002;25:1631-6.

Table III. Pearson correlations between waist circumference sites and body mass index z-score for boys (n = 32) and girls (n = 41)

R	WC1 (cm)	WC2 (cm)	WC3 (cm)	WC4 (cm)	BMI z-score
WC1 (cm)		0.93	0.95	0.99	0.58
WC2 (cm)	0.94		0.97	0.93	0.65
WC3 (cm)	0.98	0.97		0.94	0.59
WC4 (cm)	1.00	0.95	0.98		0.59
BMI z-score	0.70	0.66	0.69	0.68	

Iliac crest (WC1), narrowest waist (WC2), midpoint between floating rib and iliac crest (WC3) and umbilicus (WC4); $P < .001$ for all correlations. Boys' correlations are shown below the line; girls' correlations are shown above the line.

Table IV. Pearson correlations between waist circumference sites and body mass index z-score with metabolic risk (n = 73)

	WC1	WC2	WC3	WC4	BMI z-score
SBP (mm Hg)	0.43*	0.43*	0.43*	0.40*	0.48*
DBP (mm Hg)	0.37*	0.46*	0.45*	0.36*	0.38*
Triglycerides (mM)	0.16	0.34*	0.30*	0.18	0.22
Total cholesterol (mM)	-0.15	-0.12	-0.13	-0.15	-0.12
LDL cholesterol (mM)	-0.13	-0.16	-0.17	-0.14	-0.11
HDL cholesterol (mM)	-0.17	-0.21	-0.18	-0.18	-0.22
HOMA-IR	0.45*	0.62*	0.58*	0.46*	0.43*
Insulin (mU/L)	0.43*	0.63*	0.57*	0.44*	0.45*
Glucose (mM)	0.20	0.14	0.21	0.25*	0.06

*$P < .05$; all models were adjusted for age, sex, and ethnicity.

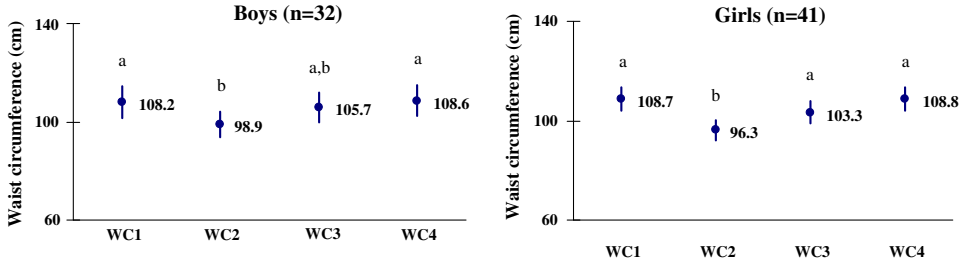

Figure 1. Mean waist circumference (95% CI) at 4 measurement sites. Superscript letters denote significant difference by measurement site within group ($P < .05$). Iliac crest (WC1), narrowest waist (WC2), midpoint between floating rib and iliac crest (WC3), and umbilicus (WC4); no sex differences were found ($P > .05$ for all).