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Review

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Influence of Waist Circumference Measurement Site on Visceral Fat and Metabolic Risk in Youth

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Although the rate of childhood obesity seems to have plateaued in recent years, the prevalence of obesity among children and adolescents remains high. Childhood obesity is a major public health concern as overweight and obese youth suffer from many co-morbid conditions once considered exclusive to adults. It is now well demonstrated that abdominal obesity as measured by waist circumference (WC) is an independent risk factor for cardiovascular disease and metabolic dysfunction in youth. Despite the strong associations between WC and cardiometabolic risk factors, there is no consensus regarding the optimal WC measurement sites to assess abdominal obesity and obesity-related health risk in children and adolescents. Currently, the WC measurement site that provides the best reflections of visceral fat and the best correlations with cardiometabolic risk factors is unclear. The purpose of this review is to explore whether WC measurement sites influence the relationships between WC, visceral fat, and cardiometabolic risk factors in children and adolescents.

Key words: Childhood obesity, Waist circumference, Visceral fat, Metabolic risk

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INTRODUCTION

Childhood obesity is one of the most serious public health concerns of the 21st century.[1] Although the rate of childhood obesity seems to have plateaued in recent years, the prevalence of obesity among children and adolescents remains high in Canada, the United States, and in east and south Asia.[2] Moreover, waist circumference (WC) in children and adolescents has increased significantly over the past two decades,[3-10] and in some countries, abdominal obesity has increased to a greater degree than overall obesity.[3,6,7,10] Given that WC is an independent predictor of low high-density lipoprotein cholesterol and high triglyceride, glucose, and insulin levels in youth,[11-14] and that overweight and obese youth are more likely to be obese in adulthood,[15,16] studies have recommended including WC in routine pediatric assessments to identify those at elevated health risks.[11-13]

A recent consensus statement by the International Atherosclerosis Society and International Chair on Cardiometabolic Risk Working Group on Visceral Obesity reinforces the use of WC in routine clinical practice to identity adults with increased abdominal obesity and cardiometabolic risk.[17] Although measuring WC in clinical settings has been recommended by leading health authorities (e.g., the World Health Organization [WHO] and the National Institutes of Health [NIH]), there is no consensus or optimal protocol for measuring WC. Currently, the NIH recommends measurement of WC at the superior border of the iliac crest,[18] whereas the WHO[19] and Health Canada[20] suggest WC measurement at the midway point between the superior border of the iliac crest and the lowest rib.

A panel of experts conducted a systematic review of 120 studies in adults to determine whether WC measurement sites (e.g., minimal waist, umbilicus, last rib, iliac crest, and midpoint) influenced the relationships of WC with cardiovascular disease (CVD) and diabetes-related morbidity with all-cause and CVD mortality and reported similar associations between these health outcomes and all WC measurement sites.[21] To date, the WC measurement site that provides the best estimations of visceral adiposity and the best associations with cardiometabolic risk factors is unclear in youth. The purpose of this review is to explore whether WC measurement site influences the relationships between WC, visceral fat, and cardiometabolic risk factors in children and adolescents.

VARIABILITY IN WAIST CIRCUMFERENCE BASED ON MEASUREMENT SITE

In adults, various WC measurement protocols exist in the literature, and the commonly used WC measurement site is based on either bony landmarks (e.g., iliac crest, last rib, and midpoint between the iliac crest and the last rib) or external landmarks (e.g., minimal waist, largest abdominal circumference, umbilicus, 1 cm above umbilicus, and 1 inch above umbilicus).[21] Studies in youth[22-25] have employed similar WC measurement locations and documented significant differences in the absolute values of WC at different measurement sites. For example, Hitze et al.[22] have measured WC at four sites (iliac crest, lowest rib, midway between the iliac crest and the lowest rib, and 4 cm above umbilicus) in 180 boys and girls (13.2 ± 3.7 years of age). Although all four WCs were strongly associated with body mass index (BMI) and percentage of body fat, measurement location significantly influenced the result ($WC_{\text{lowest rib}} < WC_{\text{4 cm above umbilicus}} < WC_{\text{midway}} < WC_{\text{iliac crest}}$), and this observation was more pronounced in girls than in boys. Further, the prevalence of abdominal obesity (WC ≥ 90th age- and sex-specific percentile) differed substantially according to measurement site. For example, in both boys and girls, prevalence of abdominal obesity was lowest for $WC_{\text{lowest rib}}$ (15.7% in boys and 13.2% in girls) and highest for $WC_{\text{iliac crest}}$ (30.3% in boys and 37.4% in girls).[22] Similarly, in a large sample of children and adolescents (n = 371, 5–18 years), Harrington et al.[24] observed substantial differences in absolute WC values across measurement sites in African American and Caucasian youth. Although all four WC measures (e.g., minimal waist, midpoint between the iliac crest and the lowest rib, superior border of the iliac crest, and the umbilicus) were highly correlated with each other (r = 0.97–0.99), difference in absolute WC value was observed in both sexes and races. Accordingly, this influenced the proportion of youth having abdominal obesity (WC ≥ 90th percentile); in boys, the prevalence of abdominal obesity varied from 16.6% to 25.1%, and in girls, the prevalence varied from 24.5% to 38.3% depending on the WC measurement site. These observations[22,24] are in line with other pediatric studies[23,25-28] reporting significant differences in WC at different measurement sites.

We are aware of three studies that examined the reliability for WC measurement at different measurement sites in children and adolescents.[22,24,29] Harrington et al.[24] showed that all four WC measures (minimal waist, midpoint between the iliac crest and the lowest rib, superior border of the iliac crest, and umbilicus) were highly reproducible, with intraclass correlation coefficients (ICCs) of inter-tester reliability between 0.989 and 0.999 and ICC for intra-test reliability between 0.983 and 0.994 across measurement sites. Further, the reproducibility of WC was not influenced by BMI or measurement site. Similarly, Hitze et al.[22] reported intra-observer coefficient of variation (CV) between four trained testers were 0.6% ($WC_{\text{lowest rib}}$), 1.5% ($WC_{\text{4 cm above umbilicus}}$), 1.1% ($WC_{\text{midway}}$), and 0.7% ($WC_{\text{iliac crest}}$). The corresponding inter-observer CVs were 1.0% ($WC_{\text{lowest rib}}$), 1.1% ($WC_{\text{4 cm above umbilicus}}$), 1.9% ($WC_{\text{midway}}$), and 3.1% ($WC_{\text{iliac crest}}$).

Although WC is a highly reproducible anthropometric measure, it is clear that discrepancies in WC measurement can significantly influence the absolute WC values, and the proportion of youth having abdominal obesity. This can be problematic, especially when WC is used for decision-making in clinical settings and when conducting comparisons between studies that employed different WC measurement protocols.[25] Therefore, it is important to adopt a standard WC measurement procedure to facilitate its use to identify youth at increased risk for CVD and type 2 diabetes mellitus (T2DM).[30]

INFLUENCE OF WC MEASUREMENT SITE ON VISCERAL FAT

WC has been well recognized as a useful marker of abdominal fat and metabolic risk factors.[11,12,31] In adults, WC is a significant predictor of metabolic syndrome, T2DM, CVD, and all-cause mortality independent of BMI.[32-35] Similarly, in children and adolescents, enlarged WC has been associated with insulin resistance, hyperinsulinemia, high blood pressure, unfavorable lipid profile, and atherogenic lipoprotein particle size independent of BMI percentile.[12-14] Although the mechanisms by which WC is associated with metabolic risk factors are unclear, the health risk predicted by WC could be explained by its ability to act as a surrogate for visceral fat,[12,34] a well-known predictor of CVD and T2DM.[36]

We are aware of only three studies in children and adolescents (Table 1)[24,28,29] that examined the influence of WC measurement site on total visceral fat volume using an imaging modality, which is the gold standard method of quantifying visceral fat. Koot et al.[29] examined the associations between two WC measurement sites (WC at midpoint between the last rib and iliac crest, narrowest WC between xiphisternum and umbilicus) and total visceral fat in 92 children and adolescents with severe obesity (8–18 years, BMI ≥35 kg/m^2) and reported that $WC_{narrowest}$ (r=0.64 in boys and r=0.68 in girls) is more strongly associated with $WC_{midpoint}$ (r=0.39 in boys and r=0.46 in girls) in both boys and girls. However, in that study,[29] more than one technician measured WC. Further, it is unclear how the technicians objectively identified the narrowest WC in youth with enlarged WC (mean $WC_{narrowest}$ = 102.9 ± 12.1 cm; mean $WC_{midpoint}$ = 114.3 ± 13.3 cm) since identifying a single narrowest WC point is difficult in those with severe abdominal obesity.

In contrast, Harrington et al.[24] showed that aged-controlled correlation coefficients (r) between all four WC measures ($WC_{umbilicus}$, $WC_{midpoint}$, $WC_{iliac\ crest}$, $WC_{minimal\ waist}$) and total visceral fat volume were similar (r ranged from 0.81 to 0.89) in both African American and Caucasian boys and girls (n=423). Likewise, Bosy-Westphal et al.[28] reported similar associations between three WC measures ($WC_{last\ rib}$, $WC_{midpoint}$, and $WC_{iliac\ crest}$) and total visceral fat in Caucasian prepubertal (r=0.65–0.76 in boys; r=0.70–0.73 in girls) and pubertal children (r=0.86–0.87 in boys; r=0.82–0.83 in girls) with a wide range of BMI. In that study,[28] there were no differences in r-values except in prepubertal boys, where the relationship between $WC_{iliac\ crest}$ and visceral fat (r=0.65) was lower than those of $WC_{midpoint}$ (r=0.74) and $WC_{last\ rib}$ (r=0.76) with visceral fat.

To date, few studies have examined the influence of WC measurement site on the measured total amount of visceral fat in children and adolescents, and their findings have been inconsistent. Although multiple-image protocols using computed tomography (CT) or magnetic resonance imaging (MRI) are considered the gold standard to quantify total visceral fat, due to cost, accessibility, and radiation exposure in the case of CT, the vast majority of studies employ a single-slice CT or MRI image at L4–L5 as a surrogate for total visceral fat.[37] Given that the relationship between WC and vis-

Table 1. Associations between waist circumference measurement sites and visceral fat in children and adolescents

Study	Number	Age (yr)	BMI (kg/m^2)	WC measurement site	Visceral fat measurement	Main finding
Harrington et al.[24]	White boy, 95 White girl, 83 African American boy, 80 African American girl, 113	5–18	23.2±6.8	(1) Umbilicus (2) Midpoint* (3) Iliac crest (4) Minimal waist	MRI (multiple-image protocol spanning from the highest point of the liver to the bottom of the right kidney)	WC measurements at four sites were significantly associated with log visceral fat in overall sample (r=0.81–0.83) and race-by-sex groups (r=0.85–0.86 in white males; r=0.81–0.82 in African American males; r=0.88–0.89 in white females; r=0.86–0.87 in African American females) after accounting for age.
Bosy-Westphal et al.[28]	Prepubertal boy, 39 Prepubertal girl, 35 Pubertal boy, 74 Pubertal girl, 86	9.3±1.6 8.8±1.5 15.0±1.9 14.8±2.1	16.7±3.0 16.7±2.4 23.3±5.9 23.3±5.7	(1) Lowest rib (2) Midpoint* (3) Iliac crest	MRI (multiple-image protocol spanning from the diaphragm to the femur heads)	Age-adjusted partial correlations between all WC measurements and log visceral fat were similar in prepubertal children (r=0.65–0.76 in boys; r=0.70–0.73 in girls) and pubertal children (r=0.86–0.87 in boys; r=0.82–0.83 in girls). However, in prepubertal boys, $WC_{iliac\ crest}$ (r=0.65) had a lower correlation with log visceral fat compared with $WC_{midpoint}$ (r=0.74) and $WC_{lowest\ rib}$ (r=0.76).
Koot et al.[29]	Children and adolescent, 92	13.9±2.2	BMI z-score, 3.3±0.3	(1) Midpoint* (2) Narrowest waist between xiphisternum and umbilicus	MRI (multiple-image protocol)	$WC_{narrowest\ waist}$ was more strongly associated with visceral fat (r=0.69 for all; r=0.64 in boys; r=0.68 in girls) compared to $WC_{midpoint}$ (r=0.51 for all; r=0.39 in boys; r=0.46 in girls) in both boys and girls.

Values are presented as mean±standard deviation.
*Midpoint between the lowest rib and the iliac crest.
BMI, body mass index; WC, waist circumference; MRI, magnetic resonance imaging.

ceral fat can be influenced by sex, pubertal stage, race, and degree of obesity,[38] more studies are needed to investigate the optimal WC measurement site that provides the best estimation of visceral adiposity in children and adolescents.

INFLUENCE OF WC MEASUREMENT SITE ON METABOLIC RISK FACTORS

In a systemic review of 120 studies (236 samples), Ross et al.[21] concluded that, although WC measurement sites varied significantly across studies, WC measurement protocol has no substantial influence on the relationships between WC, morbidity of CVD and diabetes, all-cause mortality, and CVD mortality in adult populations. Further, they reported that associations between these health outcomes and all WC measurement sites did not differ by sample size, sex, race, or ethnicity.[21] In the absence of such hard health outcomes, five studies[22,24,25,28,39] have examined the associations between WC measurement sites and cardiometabolic risk factors in youth (Table 2). In a large sample of Caucasian children and adolescents, Hitze et al.[22] showed that, in girls, WC $_{\text{iliac crest}}$ compared to WC $_{\text{lowest rib}}$ had a stronger correlation with triglycerides, whereas in boys, WC $_{\text{iliac crest}}$ compared to other WC measurement sites (WC $_{\text{lowest rib}}$, WC $_{\text{4 cm above the umbilicus}}$, and WC $_{\text{midway between lowest rib and iliac crest}}$) had a stronger relationship with low-density lipoprotein cholesterol. Similarly, Johnson et al.[25] reported that significant differences exited between four commonly recommend WC measurement sites (WC $_{\text{iliac crest}}$, WC $_{\text{narrowest}}$, WC $_{\text{midpoint}}$, and WC $_{\text{umbilicus}}$), and that not all sites were equivalently associated with metabolic risks in 73 overweight boys and girls (8–17 years, BMI ≥ 85th percentile). In that study,[25] the narrowest WC between the xiphoid process and iliac crest and the WC $_{\text{midpoint}}$ between floating rib and iliac crest were most strongly and consistently associated with metabolic syndrome defined by three criteria.[40-42] Yet others have shown that WC measurement sites did not influence the associations between WC and metabolic risk factors (e.g., fasting lipids, glucose, and blood pressure) in children and adolescents independent of sex.[24,28]

Table 2. Relationships between waist circumference measurement sites and cardiometabolic risk factors in children and adolescents

Study	Number	Age (yr)	BMI (kg/m^2)	WC measurement site	Main finding
Hitze et al.[22]	Caucasian boy, 89 Caucasian girl, 91	13.7 (10.0–16.8) 13.3 (10.0–116.8)	19.7 (17.1–121.5) 19.1 (16.5–121.0)	(1) Lowest rib (2) Umbilicus+4 cm (3) Midpoint* (4) Iliac crest	After adjusting for age and pubertal status, all WC measurements were significantly associated with cardiometabolic risk factors in both sexes. However, in girl, WC $_{\text{iliac crest}}$ (r = 0.29) had a higher correlation with triglycerides than WC $_{\text{lowest rib}}$ (r = 0.22). In boys, WC $_{\text{iliac crest}}$ (r = 0.36) had a higher correlation with LDL-C than other WC measurement sites (WC $_{\text{lowest rib}}$ vs. WC $_{\text{umbilicus}}$ vs. WC $_{\text{midway}}$; r = 0.30 vs. r = 0.30 vs. r = 0.32, respectively).
Harrington et al.[24]	White boy, 95 White girl, 83 African American boy, 80 African American girl, 113	12.3 ± 3.5	23.2 ± 6.8	(1) Umbilicus (2) Midpoint* (3) Iliac crest (4) Minimal waist	Age-adjusted correlations between all four WC measurements and metabolic syndrome risk factors were similar in all race-by-sex groups.
Johnson et al.[25]	Boy, 32 Girl, 41	12.1 ± 2.6 12.7 ± 2.6	32.8 ± 6.5 33.4 ± 6.3	(1) Umbilicus (2) Midpoint* (3) Iliac crest (4) Narrowest waist	WC $_{\text{narrowest waist}}$ and WC $_{\text{midpoint}}$ were more strongly and consistently association with metabolic risk factors (e.g., systolic and diastolic blood pressure, triglycerides, HOMA-IR, and fasting insulin) and the odds for metabolic syndrome as compared with other WC measurement sites.
Bosy-Westphal et al.[28]	Prepubertal boy, 39 Prepubertal girl, 35 Pubertal boy, 74 Pubertal girl, 86	9.3 ± 1.6 8.8 ± 1.5 15.0 ± 1.9 14.8 ± 2.1	16.7 ± 3.0 16.7 ± 2.4 23.3 ± 5.9 23.3 ± 5.7	(1) Lowest rib (2) Midpoint* (3) Iliac crest	Age-adjusted partial correlations between all WC measurements and cardiometabolic risk factors (e.g., blood pressure, fasting lipid, and glucose) were similar in both prepubertal and pubertal children.
Andaki et al.[39]	Brazilian boy, 81 Brazilian girl, 106	9.9 ± 0.7 17.6 ± 2.9	17.8 ± 3.6	(1) Umbilicus (2) Midpoint* (3) Narrowest waist	In boys, WC $_{\text{narrowest}}$ is the best predictor of low HDL-C, and in girls, WC $_{\text{umbilicus}}$ is the best predictor of hypertriglyceridemia and metabolic syndrome. WC $_{\text{midpoint}}$ is the most accurate in predicting high blood pressure in girls.

Values are presented as median (range) or mean ± standard deviation.
*Midpoint between the lowest rib and the iliac crest.
BMI, body mass index; WC, waist circumference; LDL-C, low-density lipoprotein cholesterol; HOMA-IR, homeostatic model assessment for insulin resistance; HDL-C, high-density lipoprotein cholesterol.

CONCLUSION

Abdominal obesity assessed by WC is associated with visceral fat, fatty liver, and risk factors for CVD, dyslipidemia, and T2DM in children and adolescents.[12-14,43] Accordingly, age- and sex-specific pediatric WC reference data have been developed in a number of countries including the United States,[44] Canada,[45] United Kingdom,[46] Australia,[47] China,[48] and India.[49] However, due to the differences in WC measurement protocols, comparing the prevalence of abdominal obesity between countries is not straightforward.

Limited data are available regarding the influence of WC measurement site on total visceral fat and metabolic risk factors in youth, and current evidence regarding the optimal WC measurement site to predict health risk factors is unclear and warrants further investigation. Studies[21,25] have suggested using bony landmarks such as those recommended by the WHO (e.g., midway between the superior border of the iliac crest and the lowest rib) or the NIH (e.g., WC at the superior border of the iliac crest) for practicability and reliability issues. However, identification of two landmarks, in the case of the WHO protocol, is more time-consuming and may lead to measurement errors.

Although external landmarks such as the umbilicus are easy to identify in both males and females, the location may shift with significant weight loss or gain.[25] The narrowest WC is also widely used in the literature, but it is difficult to identify when participants are very lean or abdominally obese. Thus, an expert panel group[21] suggested that the NIH WC protocol may be more easily accepted by both the practitioner and the general public. Given the significant sex and race differentials in the relationships between WC and visceral adiposity in children and adolescents,[38] more studies are needed in various racial and ethnic groups and pubertal stages. Further, longitudinal studies with serial assessments of WC at different sites and visceral fat changes may provide useful information when tracking children's growth and health risk factors over time.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Study concept and design: SL; acquisition of data: all authors; analysis and interpretation of data: all authors; drafting of the manuscript: SL; critical revision of the manuscript: all authors; administrative, technical, or material support: all authors; and study supervision: all authors.

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