

Role of Waist Measures in Characterizing the Lipid and Blood Pressure Assessment of Adolescents Classified by Body Mass Index

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Objective: To determine if the interaction of waist circumference percentile and waist to height ratio (WHtR) with body mass index (BMI) may serve to provide further risk specification in the lipid and blood pressure assessment of adolescents beyond BMI classification.

Design: Population-based, cross-sectional study. Data collected during the 2009-2010 academic school year.

Setting: Geographically and administratively defined Niagara Region, Ontario, Canada. Data collected in school, during subjects' mandatory physical education class. Part of the Heart Niagara Inc Healthy Heart Schools' Program.

Participants: Entire population of grade 9 (14- and 15-year-old) students in the Niagara Region, Ontario. Four thousand eight hundred eighty-four students enrolled in grade 9 during the study period, of which 4104 participated (51% male) and 3248 (79%) had complete data.

Main Outcome Measures: Nonfasting lipid values and blood pressure categories in subjects categorized based on BMI/waist circumference percentile and BMI/WHtR.

Results: The associations between blood pressure, lipid profile, and measures of adiposity (BMI alone, BMI/waist circumference percentile, and BMI/WHtR) were statistically significant but had a limited strength and were not statistically significant from each other. For overweight and obese subjects, increased WHtR categories were associated with worsened lipid profile and increased odds of hypertension both relative to subjects with both normal BMI and normal WHtR and subjects with normal WHtR within each BMI category.

Conclusion: Waist measures should be included in the screening and assessment of overweight and obese adolescents.

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BODY MASS INDEX (BMI) IS currently the most commonly used surrogate measure of adiposity in children. Age- and sex-specific normal values have been formulated by the International Obesity Task Force,¹ the US Centers for Disease Control and Prevention,² and the World Health Organization.³ It is an established correlate of cardiometabolic risk factors in the pediatric population^{4,5} and its measurement has been endorsed by numerous committees and organizations.^{1,2,6,7} However, BMI itself cannot differentiate between fat and fat-free mass. Therefore, an elevated BMI may not reliably reflect the accumulation of adipose tissue.⁸⁻¹¹ Waist circumference (WC) has been advocated as an indicator of abdominal fat content and has been shown to be a better indicator of visceral fat mass than BMI¹² and a marker of cardiometabolic risk.¹³⁻¹⁵ Waist to height ratio (WHtR) (WC divided by height) has been advocated as a convenient and effective indicator of abdominal adiposity.¹⁶⁻²⁰ The combined utility of WC or WHtR (waist measures) with BMI in screening for cardiometabolic risk in children has not been extensively studied. We sought to determine the role of waist measures in the lipid and blood pressure assessment of adolescents classified by BMI.

METHODS

We conducted a population-based cross-sectional study of grade 9 students (typically 14-15 years old) in the Niagara Region of Ontario, Canada. The study was undertaken in cooperation with the Heart Niagara Inc Healthy Heart Schools' Program, a curriculum enrichment program for students and schools that provides personalized information regarding car-

Table 1. Distribution of BMI and WC Percentile and WHtR

BMI/WC Percentiles	Frequency, No. (%)	BMI Percentile/WHtR	Frequency, No. (%)
BMI <85th, WC <75th	2087 (64.3)	BMI <85th, WHtR <0.5	2128 (65.5)
BMI <85th, WC 75th-<90th	76 (2.3)	BMI <85th, WHtR 0.5-<0.6	35 (1.1)
BMI <85th, WC ≥90th	0	BMI <85th, WHtR ≥0.6	0
BMI 85th-<95th, WC <75th	278 (8.6)	BMI 85th-<95th, WHtR <0.5	363 (11.2)
BMI 85th-<95th, WC 75th-<90th	198 (6.1)	BMI 85th-<95th, WHtR 0.5-<0.6	121 (3.7)
BMI 85th-<95th, WC ≥90th	9 (0.3)	BMI 85th-<95th, WHtR ≥0.6	1 (<0.1)
BMI ≥95th, WC <75th	36 (1.1)	BMI ≥95th, WHtR <0.5	102 (3.1)
BMI ≥95th, WC 75th-<90th	265 (8.2)	BMI ≥95th, WHtR 0.5-<0.6	372 (11.5)
BMI ≥95th, WC ≥90th	299 (9.2)	BMI ≥95th, WHtR ≥0.6	126 (3.9)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); WC, waist circumference; WHtR, waist to height ratio.

diometabolic risk and lifestyle that can be discussed in the classroom. The program annually targets the entire population of adolescents during their mandatory grade 9 physical education class in the geographically and administratively defined Niagara Region, Ontario. The detailed methods of the Healthy Heart Schools' Program have been previously published.²¹ All adolescents provided informed assent along with parental consent to participate in the assessment. The study protocol was approved by the research ethics boards of the Niagara Catholic District School Board and the District School Board of Niagara.

Data for this study were collected during the 2009-2010 school year. Heart Niagara staff performed all physical measurements during usual class time. The subjects underwent height and weight measurements in a standardized manner that were converted to age- and sex-specific BMI (calculated as weight in kilograms divided by height in meters squared) percentiles and z scores using the 2006 World Health Organization growth standards.³ Overweight was defined as BMI from the 85th to less than the 95th percentile and obesity was defined as BMI at or more than the 95th percentile.²² Waist circumference measurement was standardized with landmarking at the top of the posterior iliac crest with the subject standing.²³ Age- and sex-specific values were then classified into WC percentile categories (<75th, 75th-<90th, and ≥90th) based on previously published values.²⁴ The WHtR was calculated and classified into 3 categories (<0.5, 0.5-<0.6, and ≥0.6). Previous studies have suggested that a WHtR cutoff point of 0.5 is an indicator of increased cardiometabolic risk.²⁵⁻²⁷ The category of 0.5 to less than 0.6 was defined to approximately correspond to the 85th percentile within our study population and the category of 0.6 or more, with the 95th percentile. Nonfasting blood sampling by finger stick (capillary sample) was used to obtain total cholesterol and high-density lipoprotein (HDL) cholesterol levels.

Blood pressure was evaluated in a standardized manner with the subject sitting with an appropriate-sized cuff for the circumference of the adolescent's upper arm. Systolic and diastolic readings were converted to age-, sex-, and height-specific percentiles.²⁸ These values were used to classify each subject as prehypertensive (90th-<95th percentile), stage 1 hypertensive (≥95th-<99th percentile), or stage 2 hypertensive (≥99th percentile).²⁸ Adolescents with initial readings less than the 95th percentile had no further blood pressure measurements performed. Adolescents with initial blood pressure levels at the 95th percentile or more had the measurements repeated. If the second measurement was less than the 95th percentile, that value was taken and no further blood pressure measurements were performed. However, if the second measurement was at the 95th percentile or more, 6 automated readings were taken at 1-minute intervals and the average was calculated.

Data collected were analyzed and displayed as means with standard deviation and frequencies as appropriate. Subjects in

the study were classified into 2 sets of 9 groups of adiposity variables to assess the interactions between BMI and WC percentiles and BMI percentile and WHtR (**Table 1**). There were 3 groups with too few subjects for statistical analysis on their own. Rather than exclude these small groups from the analysis, they were integrated with their most similar group. The 35 subjects with a BMI less than the 85th percentile and a WHtR of 0.5 to less than 0.6 were combined with the normal group. The 9 overweight subjects with a WC of 90% or more were combined with the obese subjects with a WC of 90% or more. The 1 overweight subject with a WHtR of 0.6 or more was combined with the obese subjects with a WHtR of 0.6 or more. Therefore, 7 BMI/WC percentile and 6 BMI/WHtR groups were analyzed (there were no subjects with a normal BMI and a WC ≥90% or WHtR ≥0.6).

Total cholesterol, HDL cholesterol, and non-HDL cholesterol levels and total cholesterol to HDL cholesterol ratio and the proportion of patients with prehypertension and stage 1 and stage 2 hypertension were studied. Linear regression models were used to study the lipid variables. R² values served as an indicator of the strength of association. Ordinal logistic regression models were used to study the blood pressure categories, with C statistic values serving as an indicator of the strength of association. For both models, the groups BMI less than the 85th percentile, WC percentile less than the 75th percentile and BMI less than the 85th percentile, and WHtR less than 0.5 were used as reference categories for their respective groups. Only subjects who had BMI, WC percentile, WHtR, and blood pressure and cholesterol measurements were included in the analyses. All statistical analyses were performed using SAS statistical software version 9.2 (SAS Institute Inc).

RESULTS

A total of 4884 students were enrolled in grade 9 during the study period, and 4104 subjects (84%) participated in the study (51% male) of which 3248 of 4104 (79%) had complete anthropomorphic and clinical data (Table 1). The demographic and anthropometric distribution among subjects with incomplete data was similar to the rest of the study population. The majority of missing data were owing to subject refusal to have blood sampled. Female subjects had lower odds of being in a higher BMI (odds ratio, 0.79; *P* = .001) or WC percentile (odds ratio, 0.65; *P* < .001) category.

Overall, the association between blood pressure, lipid profile, and measures of adiposity (BMI alone, BMI/WC percentile, and BMI/WHtR) were statistically signifi-

Table 2. Patient Characteristics by Adiposity Category

	Mean (SD)						P Value
	BMI <85th, WHtR <0.5	BMI 85th-<95th, WHtR <0.5	BMI 85th-<95th, WHtR 0.5-<0.6	BMI ≥95th, WHtR <0.5	BMI ≥95th, WHtR 0.5-<0.6	BMI ≥95th, WHtR ≥0.6	
Sample size	2163	363	121	102	372	127	
Male, No. (%)	1031 (48)	194 (53)	52 (43)	64 (63)	209 (56)	75 (59)	<.001
Age, y	14.6 (0.5)	14.6 (0.5)	14.6 (0.5)	14.6 (0.5)	14.5 (0.5)	14.6 (0.8)	.59
BMI	19.8 (1.8)	23.9 (0.9)	24.3 (1.1)	26.4 (1.3)	28.6 (2.4)	34.2 (4.6)	
WC, cm	70 (5)	78 (5)	85 (4)	82 (5)	92 (7)	107 (9)	
WHtR	0.42 (0.03)	0.46 (0.02)	0.52 (0.02)	0.48 (0.02)	0.55 (0.03)	0.65 (0.05)	
Systolic blood pressure, mm Hg	103 (10)	107 (11)	105 (10)	112 (10)	112 (10)	113 (11)	<.001
Hypertension, No. (%)							
Normotension (<90th percentile)	2033 (94)	338 (93)	112 (93)	88 (86)	309 (83)	88 (69)	<.001
Prehypertension (<95th percentile)	77 (4)	15 (4)	7 (6)	11 (11)	37 (10)	18 (14)	
Stage 1 (>95th percentile)	43 (3)	7 (2)	2 (2)	2 (2)	22 (6)	17 (14)	
Stage 2 (>99th percentile)	10 (<1)	3 (1)	0	1 (1)	4 (1)	4 (3)	
Total cholesterol level, mmol/L	3.80 (0.71)	3.82 (0.71)	4.03 (0.79)	3.87 (0.82)	4.02 (0.81)	4.22 (0.82)	<.001
HDL cholesterol level, mmol/L	1.28 (0.32)	1.18 (0.32)	1.19 (0.36)	1.12 (0.30)	1.06 (0.29)	0.99 (0.25)	<.001
Non-HDL cholesterol, mmol/L	2.52 (0.66)	2.64 (0.69)	2.85 (0.79)	2.75 (0.79)	2.97 (0.82)	3.23 (0.80)	<.001
Total cholesterol to HDL cholesterol ratio	3.13 (0.96)	3.47 (1.33)	3.77 (1.76)	3.64 (1.05)	4.11 (1.51)	4.53 (1.36)	<.001
Total cholesterol classification, No. (%)							
Normal	1725 (81)	285 (79)	93 (77)	79 (77)	267 (72)	76 (60)	<.001
Borderline (≥4.4 to <5.2 mmol/L)	33 (15)	66 (18)	16 (13)	18 (18)	72 (19)	38 (29)	
High (≥5.2 mmol/L)	77 (4)	12 (3)	12 (10)	5 (5)	33 (9)	14 (11)	
Non-HDL cholesterol classification, No. (%)							
Normal	1791 (83)	283 (78)	86 (71)	77 (75)	226 (61)	55 (43)	<.001
Borderline (≥3.10 to <3.75 mmol/L)	272 (13)	56 (15)	23 (19)	15 (15)	85 (23)	40 (32)	
High (≥3.75 mmol/L)	100 (5)	24 (7)	12 (10)	10 (10)	61 (16)	32 (25)	

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); HDL, high-density lipoprotein; WC, waist circumference; WHtR, waist to height ratio.

SI conversion factor: To convert total cholesterol and HDL cholesterol to milligrams per deciliter, divide by 0.0259.

cant ($P < .05$) but with limited strength (R^2 values from linear regression models for lipid profile ranged from 0.06-0.13; C statistics from ordinal logistic regression for degree of hypertension ranged from 0.61-0.64). There were no relevant differences in model performance between models with BMI alone, BMI with WC percentile, and BMI with WHtR. Additional analyses will be focusing on the association between lipid profile/blood pressure and BMI/WHtR.

Patient characteristics stratified by BMI/WHtR categories are presented in **Table 2**. In multivariable regression models adjusted for subjects' age and sex, for overweight and obese subjects, increasing WHtR categories corresponded with worsening lipid profile, with the greatest associations occurring in the obese subjects (**Figure 1**). Obese subjects had increased odds of a higher degree of hypertension. Of obese subjects, those with an increased WHtR had further increased odds of hypertension relative to those subjects with more normal waist measures (**Figure 2**).

COMMENT

Our study sought to investigate the role that waist measures serve in the lipid and blood pressure assessment of adolescents categorized by BMI. We found that overweight and obese adolescents with increased waist measures had worsened lipid profiles relative to those with waist measures in a lower category, with the greatest associations seen in obese subjects. In addition, obese subjects had increased odds of a higher hypertension cat-

egory across waist measures. The majority of overweight subjects had waist measures in the lower category. Both this population group and obese adolescents with lower waist measures tended to have a significantly elevated mean lipid value relative to subjects with normal BMI and waist measure. Future studies are required to assess whether this statistically increased risk is clinically relevant. The smallest proportion of subjects were those who had a normal BMI but were in a higher waist measure category, indicating that normal-weight subjects were unlikely to have higher levels of visceral or central adiposity. In addition, these subjects did not appear to have worsened lipid or blood pressure values.

The R^2 and C statistic values for the various adiposity indicators in our study were low. This may be partly because lipid values and blood pressure measurements are based on a number of risk factors in addition to anthropometric measurements. Waist circumference percentile and WHtR were found to have similar R^2 and C statistic values when used both independently and when interacting with BMI. Given that WHtR has been promoted as a convenient, standardized, and easy-to-use marker, with a consistent guideline advocated from childhood into adulthood (keep the WHtR <0.5),²⁶ WHtR may be more applicable in clinical practice than WC percentile and may optimize patient education and tracking of risk.

Though guidelines from the major Canadian, American, and British medical associations acknowledge the potential added benefits of the use of waist measures, they are not in full agreement with respect to their use in screening the pediatric population. The 2007 American

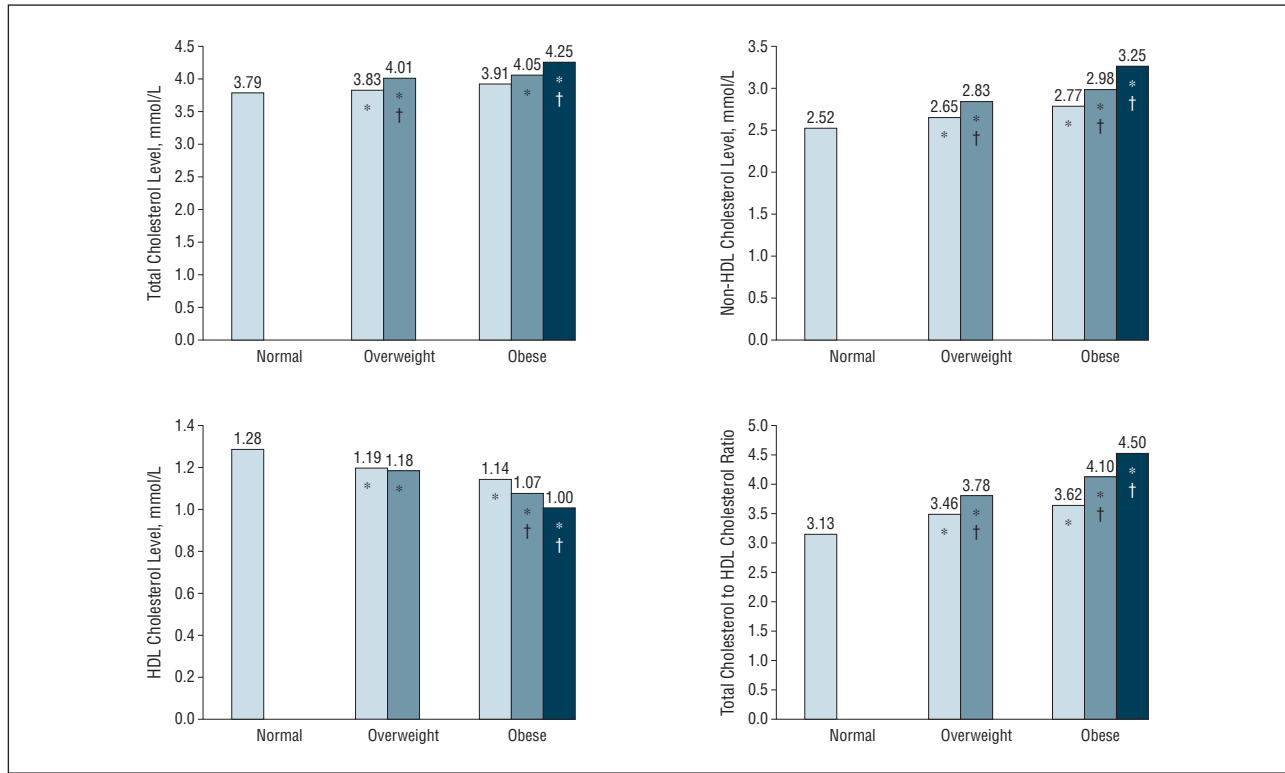


Figure 1. Mean values of lipid variables across body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared) and waist to height ratio (WHtR) categories, adjusted for age and sex. Normal: BMI less than the 85th percentile; overweight: BMI in the 85th to less than the 95th percentile; obese: BMI in the 95th percentile or more; light gray: WHtR less than 0.5; dark gray: WHtR 0.5 to less than 0.6; and black: WHtR 0.6 or more. *Statistically significant values ($P < .05$) relative to the BMI less than the 85th percentile and WHtR less than 0.5 category. †Statistically significant values ($P < .05$) relative to subjects with a WHtR less than 0.5 within that given BMI category. SI conversion factor: To convert total cholesterol and high-density lipoprotein (HDL) cholesterol to milligrams per deciliter, divide by 0.0259.

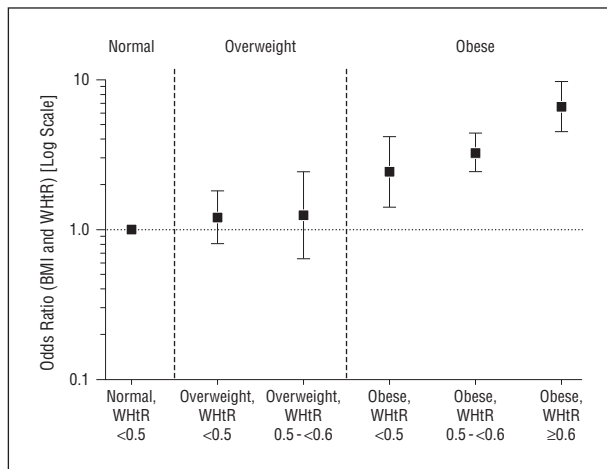


Figure 2. Odds ratios for a higher blood pressure category (normal vs prehypertension vs hypertension) for the body mass index (BMI) and waist to height ratio (WHtR) categories, adjusted for age and sex. Only the last 2 categories were significantly different than normal (odds ratio, 3.2; $P = .003$; odds ratio, 7.2; $P < .001$), and both were different from each other (odds ratio, 2.3; $P = .001$). Normal: BMI less than the 85th percentile; overweight: BMI in the 85th to less than the 95th percentile; obese: BMI in the 95th percentile or more. Error bars represent the 95% confidence interval.

Medical Association, Centers for Disease Control and Prevention, and American Academy of Pediatrics joint statement commented that WC measurements are difficult to standardize and appropriate normal values are uncertain.²⁹ The 2006 Canadian clinical practice guidelines on

the management and prevention of obesity in adults and children recommend the measurement of BMI and WC in all adults and adolescents.^{30,31} The 2006 National Institute for Health and Clinical Excellence guidelines from the United Kingdom did not recommend the use of WC as a routine measure in children but indicated that it may be used to give additional information regarding risk of developing other long-term health problems.³² Our present study shows that the incorporation of waist measures in the assessment of adolescents improves the risk stratification of lipid and blood pressure values, indicating that waist measures should be considered in the routine pediatric assessment.

In 1 report from the Bogalusa Heart Study of a cross-sectional sample of children aged 5 to 18 years,³³ subjects were categorized based on their BMI and defined as having a high or low WC, based on a predicted WC calculated through a stepwise regression model. Jansen et al³³ concluded that BMI and WC were useful together when used in a categorized fashion, but when used as continuous variables, the added contribution above the use of either marker individually was minimal and of no clinical significance. In contrast, we categorized WC independent of BMI, using percentile categories of published normal values. This allowed us to identify a large group of overweight adolescents with more normal waist measures.

Mokha et al,¹⁶ using subjects from the Bogalusa Heart Study, found that a high WHtR identified increased car-

diometabolic risk factor variables (mean arterial blood pressure, lipid values, and glucose and insulin levels) in subjects with a normal BMI, and a low WHtR was protective in the overweight/obese population. For example, the odds of children with normal BMI with central obesity having adverse HDL cholesterol levels were 2.01 (based on multivariate analysis) relative to children with normal BMI without central adiposity. Overweight/obese children without central adiposity had an odds ratio of 0.53 relative to their central adiposity counterparts for adverse HDL cholesterol levels. In contrast, our study did not identify a large group of subjects with a normal BMI and elevated waist measure. Those few subjects who were classified in this category did not appear to have a significantly altered lipid profile or increased odds of a higher hypertension category, though the small number of subjects in these categories may have limited the precision of the results.

Freedman et al,³⁴ using data from the Bogalusa Heart Study, found a wide range of body fatness among overweight children, indicating that BMI may not be an accurate predictor of adiposity. Our study similarly showed a wide range of waist measures among overweight adolescents, the majority of whom had lower waist measures. Freedman et al found that overweight children with a relatively high WHtR had an odds ratio of approximately 2 to 3 relative to overweight children without increased WHtR for most risk factors studied. The study concluded that WHtR performed better than skinfold thickness and BMI for age as a second screening tool.

Bassali et al,³⁵ in studying an obese biracial population, found obese children with a WC of 90% or more to have an odds ratio of 3 to 4 for adverse levels of lipids and fasting insulin levels, relative to those with a normal WC. Our study showed trends of worsening mean lipid values and higher odds of a higher blood pressure category with increasing waist measures across overweight and obese subjects, with the greatest associations seen in the obese population.

There were a number of potential limitations in the present study that should be taken into consideration when interpreting the results. Because this was a cross-sectional study, only associations but not correlations can be observed. Though universal testing in the school setting provides a large and representative study sample, we were unable to obtain multiple blood pressure measurements on all students and were unable to obtain fasting lipid profile assessments. However, nonfasting lipid levels have been previously used in large-scale population-based studies³⁶ and non-HDL cholesterol level has been shown to be an indicator of cardiometabolic risk in nonfasting persons.³⁷⁻⁴⁰ In addition, the need for fasting in lipid screening has recently been questioned in the pediatric population.⁴¹ Point-of-care lipid profile measurements rather than venous blood sampling was used. The Cholestech LDX system has previously been shown to be appropriate and validated in this type of setting.⁴²⁻⁴⁴ Our inability to perform fasting assessments precluded us from obtaining fasting glucose or insulin measurements, 2 measures that have associations with central fat distribution.¹⁴ In addition, WC measurements have been shown to have strong interobserver variability,⁴⁵ and the

WC age- and sex-specific percentiles were obtained from the US National Health and Nutrition Examination Survey data.²⁴ Therefore, these normalized values may not be completely applicable for our study population. However, our finding that WHtR showed equivalent associations as with WC percentile suggests that the National Health and Nutrition Examination Survey WC data may have been appropriate. In our statistical analysis, we elected to use a model that optimized clinical applicability and was based on previously established cutoffs. This may have weakened the strength of our analysis. Finally, racial, ethnic, and pubertal stage information of the subjects were not recorded.

In conclusion, waist measures serve to further specify lipid and blood pressure assessments in overweight and obese adolescents, with the greatest associations noted for obese adolescents. Subjects with normal BMI were found to have a low likelihood of increased central adiposity. The cardiometabolic risk of overweight and obese subjects with lower waist measures needs to be further explored with prospective longitudinal studies using standardized diagnostic evaluations. Waist to height ratio was as strong as WC percentile in its association with cardiometabolic risk and, given its convenience and consistency of threshold values, may serve as a useful clinical marker for both families and physicians to follow. Waist measures appear to be important discriminating measurements when assessing lipid and blood pressure measurements in adolescents with high BMI and should be included when screening for cardiometabolic risk in overweight and obese adolescents.

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