

Body Mass Index, Waist Circumference, and Clustering of Cardiovascular Disease Risk Factors in a Biracial Sample of Children and Adolescents

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ABSTRACT. *Objective.* To derive optimal body mass index (BMI) and waist circumference thresholds for children and adolescents, to predict risk factor clustering.

Design. Cross-sectional receiver operating characteristic curve analysis.

Setting. The Bogalusa Heart Study, a community-based study of cardiovascular disease risk factors in early life.

Participants. A total of 2597 black and white children and adolescents, 5 to 18 years of age, who were examined between 1992 and 1994.

Main Outcome Measures. The presence or absence of ≥ 3 age-adjusted risk factors (low high-density lipoprotein cholesterol level, high low-density lipoprotein cholesterol level, high triglyceride level, high glucose level, high insulin level, and high blood pressure) was predicted from age-adjusted BMI and waist circumference values.

Results. The areas under the receiver operating characteristic curves were significantly different from 0.5 for both BMI and waist circumference for all gender/race groups, ranging from 0.73 to 0.82. The optimal BMI thresholds were at the 53rd and 50th percentiles for white and black male subjects, respectively, and at the 57th and 51st percentiles for white and black female subjects, respectively. Similarly, the optimal waist circumference thresholds were at the 56th and 50th percentiles for white and black male subjects, respectively, and at the 57th and 52nd percentiles for white and black female subjects, respectively. The sensitivity and specificity at the thresholds were similar for all gender/race groups, ranging from 67% to 75%.

Conclusions. The use of BMI and waist circumference for the prediction of risk factor clustering among children and adolescents has significant clinical utility. In this sample, race and gender differences in the optimal thresholds were minimal. *Pediatrics* 2004;114:e198–e205. URL: <http://www.pediatrics.org/cgi/content/full/114/2/e198>; Bogalusa Heart Study, LMS regression, clinical, obesity.

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ABBREVIATIONS. BMI, body mass index; ROC, receiver operating characteristic; CDC, Centers for Disease Control and Prevention.

The most recent United States National Institutes of Health clinical guidelines for the identification and treatment of overweight and obesity among adults recognize the importance of including measurements of both overall adiposity and abdominal obesity when assessing obesity-related health risks.¹ The body mass index (BMI) is used as an indicator of overall adiposity, whereas waist circumference has been advocated as an indicator of central obesity because it is a good predictor of abdominal fat^{2,3} and is related to the development of cardiovascular diseases, type 2 diabetes mellitus, and premature death.^{4–7}

The use of BMI to classify children and adolescents as normal weight, overweight, or obese has a long history. Distributional cutoff values, such as the 85th or 95th percentiles of reference data, have been used most often.⁸ More recently, age- and gender-specific cutoff values that are tied to the adult overweight (25 kg/m²) and obesity (30 kg/m²) thresholds were developed with an international sample.⁹ Although they are based on adult obesity-related health risks, the clinical utility of these cutoff values for the identification of elevated cardiovascular disease risks among adolescents was demonstrated recently.¹⁰ There is a need to refine the prediction of obesity-related health risks among children and adolescents by using the BMI.

According to the National Institutes of Health guidelines, adult men and women with waist circumferences of >102 cm and >88 cm, respectively, are considered to be at higher risk of obesity-related disorders than are those with smaller measurements.¹ Recent studies demonstrated that these cutoff values are useful for predicting metabolic risks among men and women.^{11,12} However, there are currently no guidelines for the classification of obesity-related health risks among children and adolescents by using waist circumference.

Risk factors tend to cluster together for individuals, among both children^{13,14} and adults.¹⁵ The occurrence of multiple risk factors in adulthood predisposes subjects to elevated risks of cardiovascular diseases and premature death.^{16,17} Because clusters of risk factors for cardiovascular disease are fairly stable characteristics that tend to track fairly well

from childhood into adulthood,^{18,19} the identification of children and adolescents with elevated risk factor profiles is of great interest.

The purpose of this study was twofold. First, optimal BMI thresholds were developed for the purpose of comparing their utility with that of the waist circumference thresholds, as well as current BMI cutoff values, for the classification of overweight and obesity.^{9,20} Second, because there is a dearth of information on the clinical utility of waist circumference in addressing obesity-related health risks among children and adolescents, optimal waist circumference thresholds for this group were developed for the purpose of predicting risk factor clustering. These thresholds provide an indication of waist circumference levels at which risk factors become elevated and may be used provisionally to identify children and adolescents with poor risk factor profiles.

METHODS

Study Population

The Bogalusa Heart Study is a community-based, longitudinal study of cardiovascular disease risk factors among schoolchildren and young adults, established in 1973. Seven cross-sectional studies of schoolchildren were conducted between 1973 and 1994 in the biracial population (65% white and 35% black) of ward 4 (Bogalusa, LA) of Washington Parish. The present analysis was limited to a cross-sectional sample of 2597 children and adolescents, 5 to 18 years of age, who were examined between 1992 and 1994. The exact ages of the participants were calculated from birth and observation dates. Informed consent was obtained from all participants, and study protocols were approved by the human subjects review committees of the Louisiana State University School of Medicine and the Tulane University School of Public Health and Tropical Medicine.

General Examination

Height and weight were measured in duplicate, to the nearest 0.1 cm and 0.1 kg, respectively, and the average of the 2 measurements was used to calculate the BMI. No adjustments were made for the weight of underclothing or socks worn during the examination. Waist circumference was measured in triplicate, midway between the lowest rib and the superior border of the iliac crest, with a flexible tape. The average of the 3 waist circumference measurements was used in all analyses. Systolic and diastolic (4th phase) blood pressures were measured in 6 replicates by 2 randomly assigned nurses, on the right arm of participants in a seated relaxed position. The means of the 6 blood pressure measurements were used in all analyses. The intra-class (within-observer) correlation coefficients, based on pairs of replicate measurements made by the same observer on the same day for a 10% random subsample, were >0.99 for BMI, 0.97 for waist circumference,²¹ 0.88 for systolic blood pressure, and 0.80 for diastolic blood pressure.²²

Laboratory Analyses

Participants were asked to fast for 12 hours before a blood sample was obtained for determination of blood lipid and glucose concentrations. Cholesterol and triglyceride levels were measured by using enzymatic procedures, with an Abbott VP analyzer (Abbott Laboratories, North Chicago, IL). Serum lipoprotein levels were assayed by using a combination of heparin-calcium precipitation and agar-agarose gel electrophoresis procedures.²³ The laboratory met performance criteria and is being monitored for precision and accuracy by the Lipid Standardization and Surveillance Program of the Centers for Disease Control and Prevention (CDC) (Atlanta, GA). Plasma glucose levels were measured by using a glucose oxidase method, with a Beckman glucose analyzer (Beckman Instruments, Fullerton, CA). Plasma insulin concentrations were measured with a radioimmunoassay procedure (Phaadebas insulin kit; Pharmacia Diagnostics AB, Piscataway, NJ).

Statistical Analyses

A global risk factor cluster score was assigned to each participant on the basis of the presence or absence of up to 6 age-adjusted risk factors [low high-density lipoprotein cholesterol level, high low-density lipoprotein cholesterol level, high triglyceride level, high glucose level, high insulin level, and high blood pressure (either systolic blood pressure or diastolic blood pressure)]. Because age differences in the risk factors used in this study have been documented in the Bogalusa Heart Study,^{24,25} each of the cardiovascular disease risk variables was regressed with up to a full cubic polynomial with respect to age (age, age², and age³) for the 4 gender/race groups, using forward stepwise regression. Variables were allowed to enter and leave the model at the $P < .05$ level. Each of the age-adjusted risk variables was then divided into quintiles (20% per group), and the highest quintile (lowest quintile for high-density lipoprotein cholesterol level) was designated the elevated-risk group. The number of risk variables in the high-risk quintile that each participant demonstrated was used to classify the participant as having either a normal (<3 risk factors) or elevated (3–6 risk factors) risk factor cluster score.

BMI and waist circumference were regressed with up to a full cubic polynomial with respect to age (age, age², and age³) for the 4 gender/race groups separately, using forward stepwise regression. The standardized residuals were retained to represent age-adjusted values. Receiver operating characteristic (ROC) curves were then used to identify the optimal, age-adjusted, standardized waist circumference and BMI thresholds to predict the elevated risk cluster group (≥ 3 risk factors) in the 4 gender/race groups separately. ROC curves calculate the sensitivity (probability of correctly detecting true-positive results) and specificity (probability of correctly detecting true-negative results) of the screening measure for a range of cutoff points or thresholds. The development of ROC curves allows the identification of the optimal cutoff that maximizes both specificity and sensitivity, which can be observed as the point closest to the top left corner of the ROC graph. The areas under the ROC curves were calculated, and the null hypothesis that the area under the curve was 0.5 (predictive ability no better than chance) was tested.

The corresponding percentile value for each of the standardized waist circumference and BMI thresholds was calculated and smoothed by using LMS regression.^{26,27} The LMS method involves summarizing percentiles at each age on the basis of Box-Cox power transformations, which are used to normalize the data. The final percentile curves are the result of smoothing 3 age-specific curves, termed L (λ), M (median), and S (coefficient of variation). Data management and preliminary statistical analyses were performed with SAS version 8.02 (SAS, Cary, NC), and the ROC analyses were conducted with SPSS version 11.0.1 (SPSS, Chicago, IL).

RESULTS

The descriptive characteristics of the sample are presented in Table 1. The prevalence of overweight (using BMI of 85th percentile on CDC growth charts) ranged from 29% to 33% for the 4 gender/race groups. There were no differences in the mean age, BMI, or diastolic blood pressure among the race and gender groups; however, most traits did vary with race and/or gender. Therefore, all additional analyses were stratified according to gender and race. The percentages of participants classified as having an elevated risk factor profile (≥ 3 risk factors) were 18.2% for white male subjects, 17.3% for black male subjects, 16.5% for white female subjects, and 16.6% for black female subjects.

The gender- and age-specific ROC curves are presented in Fig 1. The optimal threshold values for predicting the elevated-risk group are those closest to the upper left corner in each panel, determined by choosing the point at which the sensitivity and specificity curves crossed. As outlined in Table 2, the areas under the curves for both BMI and waist cir-

TABLE 1. Sample Sizes and Mean \pm SD Levels of Age and Cardiovascular Risk Factors Among Children and Adolescents 5 to 18 Years of Age, According to Race and Gender

Variable	White Male	Black Male	White Female	Black Female
No.	742	510	771	574
Age (y)	11.6 \pm 3.1	11.6 \pm 3.5	11.6 \pm 3.4	11.4 \pm 3.5
BMI (kg/m ²)	20.2 \pm 4.9	20.1 \pm 4.9	20.1 \pm 4.9	20.4 \pm 5.5
Waist circumference (cm)	70.1 \pm 14.0	67.4 \pm 12.7*	65.5 \pm 12.0†	66.0 \pm 12.3
Systolic blood pressure (mm Hg)	103.2 \pm 9.3	103.6 \pm 10.6	101.5 \pm 9.6†	102.2 \pm 9.6†
Diastolic blood pressure (mm Hg)	62.0 \pm 8.6	61.5 \pm 8.9	62.7 \pm 8.6	62.1 \pm 9.6
LDL cholesterol (mmol/L)	2.58 \pm 0.62	2.67 \pm 0.73*	2.68 \pm 0.65†	2.72 \pm 0.68
HDL cholesterol (mmol/L)	1.30 \pm 0.27	1.51 \pm 0.34*	1.27 \pm 0.27†	1.46 \pm 0.33*†
Triglycerides (mmol/L)	0.93 \pm 0.51	0.71 \pm 0.31*	1.02 \pm 0.56†	0.76 \pm 0.31*†
Glucose (mmol/L)	4.54 \pm 0.36	4.46 \pm 0.44*	4.40 \pm 0.39†	4.35 \pm 0.46*†
Insulin (pmol/L)	73.3 \pm 48.2	74.3 \pm 53.5	83.6 \pm 56.1†	96.9 \pm 72.0*†
Overweight prevalence (%)‡	33.4	29.4	32.2	32.1

LDL indicates low-density lipoprotein, HDL, high-density lipoprotein.

* $P < .05$ for difference between races, within a gender.

† $P < .05$ for difference between genders, within a race.

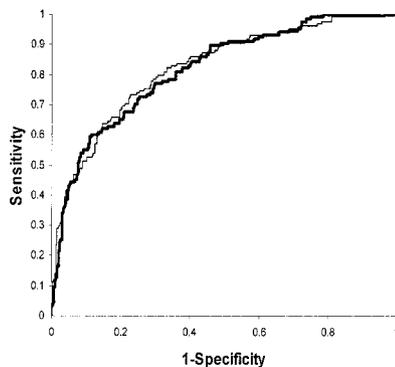
‡ Overweight prevalences were calculated by using the CDC 85th percentile BMI cutoff values.²⁰

cumference were significantly different from 0.5 ($P < .0001$) for all gender/race groups, ranging from 0.73 to 0.82. The BMI residual thresholds ranged from 0 to 0.17 SD units, whereas the waist circumference standardized residual thresholds ranged from 0 to 0.18 SD units. The optimal thresholds for both BMI and waist circumference were at or above the median for all gender/race groups, ranging from percentile 50 to 57.1. The sensitivity and specificity at the thresholds

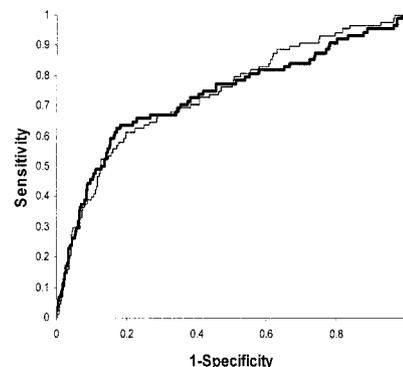
were similar for all gender/race groups, ranging from ~67% to 75%.

Table 3 presents the smoothed, age-specific, BMI and waist circumference thresholds according to gender and race. These cutoff values were derived by smoothing the percentiles derived from the ROC analysis by using LMS regression. These values are those above which there is an increased probability of being in the high risk factor cluster group. The

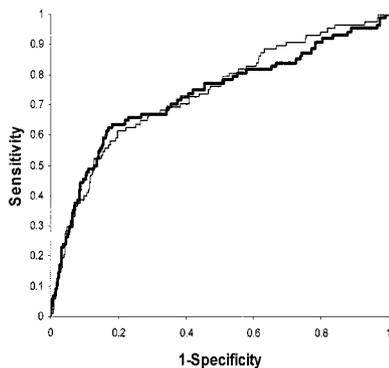
A) White Males



B) Black Males



C) White Females



D) Black Females

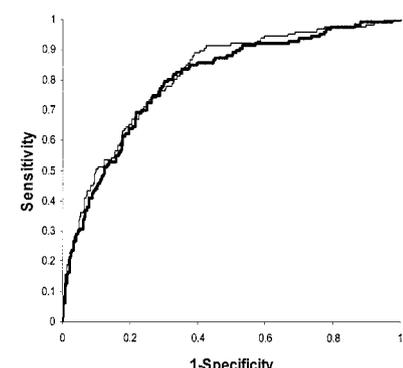


Fig 1. ROC curves for age-adjusted BMI (thick lines) and waist circumference (thin lines) with risk factor clustering among white male subjects (A), black male subjects (B), white female subjects (C), and black female subjects (D) 5 to 18 years of age, in the Bogalusa Heart Study (1992–1994).

TABLE 2. Results of ROC Curve Analyses Predicting Optimal Waist Circumference and BMI Thresholds for Risk Factor Clustering Among 5- to 18-Year-Old Children and Adolescents

	Area Under the Curve	95% CI	Residual Threshold (SD Units)	Percentile	Sensitivity (%)	Specificity (%)
BMI						
White male	0.82	0.78–0.86	0.07	52.8	72.6	72.5
Black male	0.73	0.67–0.80	0.00	50.0	67.0	66.8
White female	0.80	0.76–0.84	0.17	56.7	74.0	73.6
Black female	0.76	0.70–0.81	0.02	50.8	70.5	69.9
Waist circumference						
White male	0.82	0.78–0.86	0.14	55.6	74.8	74.5
Black male	0.74	0.67–0.80	0.00	50.0	68.2	67.5
White female	0.81	0.77–0.85	0.18	57.1	74.0	73.8
Black female	0.77	0.72–0.83	0.06	52.4	71.6	71.4

CI indicates confidence interval.

TABLE 3. Optimal Waist Circumference and BMI Thresholds for Predicting Risk Factor Clustering Among Children and Adolescents

Age (y)*	Threshold							
	BMI (kg/m ²)				Waist Circumference (cm)			
	White Male	Black Male	White Female	Black Female	White Male	Black Male	White Female	Black Female
5	15.6	16.1	15.3	15.3	52.4	51.7	50.6	51.6
6	16.1	16.3	15.9	15.7	54.1	53.5	52.7	53.3
7	16.5	16.5	16.6	16.2	56.0	55.4	55.0	55.1
8	16.9	16.8	17.5	16.9	58.3	57.4	57.6	57.3
9	17.5	17.3	18.4	17.5	61.1	59.4	60.5	59.6
10	18.3	17.8	19.1	18.2	64.4	61.6	63.3	62.0
11	19.1	18.4	19.9	19.0	67.8	63.9	65.8	64.4
12	20.0	19.1	20.5	19.8	71.3	66.4	68.0	66.6
13	20.7	19.9	21.1	20.5	74.2	69.0	69.7	68.4
14	21.3	20.7	21.6	21.3	76.4	71.5	70.9	70.0
15	21.8	21.5	21.9	22.1	77.9	73.9	71.3	71.5
16	22.1	22.3	22.1	22.9	79.0	76.0	71.3	72.8
17	22.5	23.1	22.4	23.5	79.8	77.9	71.3	73.8
18	22.7	23.7	22.7	24.1	80.4	79.5	71.2	74.7

Thresholds have been smoothed by LMS regression.

* Thresholds calculated with whole ages at the mid-year (ie, 5 years = 4.50–5.49 years).

smoothed thresholds are plotted against age and presented according to gender and race in Fig 2. The curves were quite similar for all groups; however, white male subjects tended to have a higher waist circumference threshold than the other groups, particularly after the age of 10 years.

The derived thresholds for BMI are compared with reference data currently used to classify children and adolescents as overweight or obese in Fig 3. The thresholds derived in this study for the prediction of elevated risk factors were lower than the reference criteria used for the identification of overweight and obesity. The sensitivity and specificity of the various BMI cutoff values are presented in Table 4. Both the international obesity cutoff and the CDC 95th percentile have low sensitivity (30.7–57.8%) and high specificity (88.7–93.7%), which means that they miss a large number of participants who are in the elevated-risk group; however, they do not incorrectly classify many participants as being at elevated risk when they are not. The international overweight cutoff, the CDC 85th percentile, and the thresholds derived in this study all have similar sensitivities (63.2–73.2%) and specificities (74.1–79.6%); however, the thresholds obtained in this study are more sensitive and less specific than the other 2 cutoff values. It should

be noted that the sensitivities and specificities for this study presented in Table 4 do not exactly match the values in Table 2 because the former values are based on the whole-year cutoff values presented in Table 3, rather than the entire range of data used in the ROC analyses.

DISCUSSION

This study presents optimal BMI and waist circumference thresholds for the prediction of risk factor clustering for black and white male and female subjects from the Bogalusa Heart Study. A marked strength of this study is the availability of measured risk factor data for a large biracial sample of children and adolescents. The derived thresholds were able to predict the elevated-risk group quite well, because 67% to 75% of participants were correctly classified as having an elevated risk score (sensitivity) or not having an elevated risk score (specificity). The ROC curves for BMI and waist circumference were quite similar (Fig 1), and clinical utility did not differ between the 2 anthropometric indicators.

The derivation of BMI thresholds in this study builds on earlier studies that documented a relationship between BMI and cardiovascular disease risk factors among children and adolescents.^{10,22,28–33} The

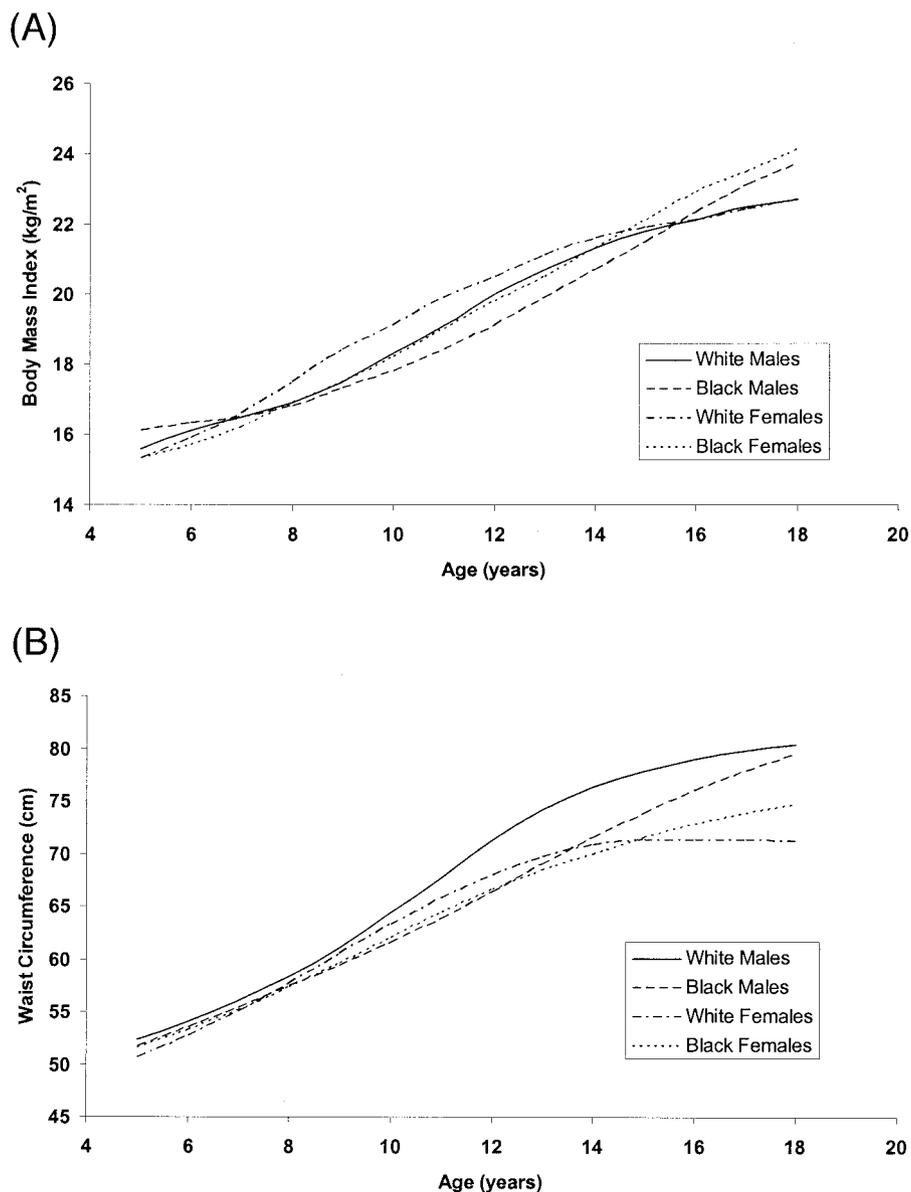


Fig 2. Smoothed BMI (A) and waist circumference (B) thresholds for predicting risk factor clustering among children and adolescents in the Bogalusa Heart Study (1992–1994).

derived threshold falls below the 85th percentile of the US CDC growth charts²⁰ and the international overweight thresholds⁹ (Fig 3). As expected, the derived thresholds demonstrate higher sensitivity and lower specificity, compared with the existing reference cutoff values (Table 4). The 95th percentile from the US CDC growth charts and the international obesity threshold have high specificity but low sensitivity, in comparison with the 85th percentile, the international overweight threshold, and the thresholds developed in this study. These comparisons have important implications. If the intent of using the BMI thresholds is to identify children and youths at increased health risk for the purpose of intervening with strategies to promote healthy lifestyles, then the lower thresholds (85th percentile or overweight threshold) could be used, because many children and adolescents with an elevated risk factor profile would be missed with the higher thresholds (95th

percentile or obesity threshold). However, if there is concern about incorrectly labeling and stigmatizing children as obese when they may not be truly at risk, then the higher thresholds could be used because of their high specificity.

Although waist circumference percentiles have been developed for Italian,³⁴ British,³⁵ and Spanish³⁶ children, we are aware of only 1 study that attempted to derive waist circumference thresholds for children on the basis of the relationship with risk factors.³⁷ In that study, waist circumference was used to predict the presence or absence of the metabolic syndrome, defined as ≥ 4 cardiovascular disease risk factors, for a sample of 140 Spanish children (mean age: 11 years). The optimal waist circumference threshold corresponded to the 70th percentile, with a sensitivity of 0.76 and a specificity of 0.81; however, age-specific waist circumference values were not presented.³⁷ Taken together, the results of

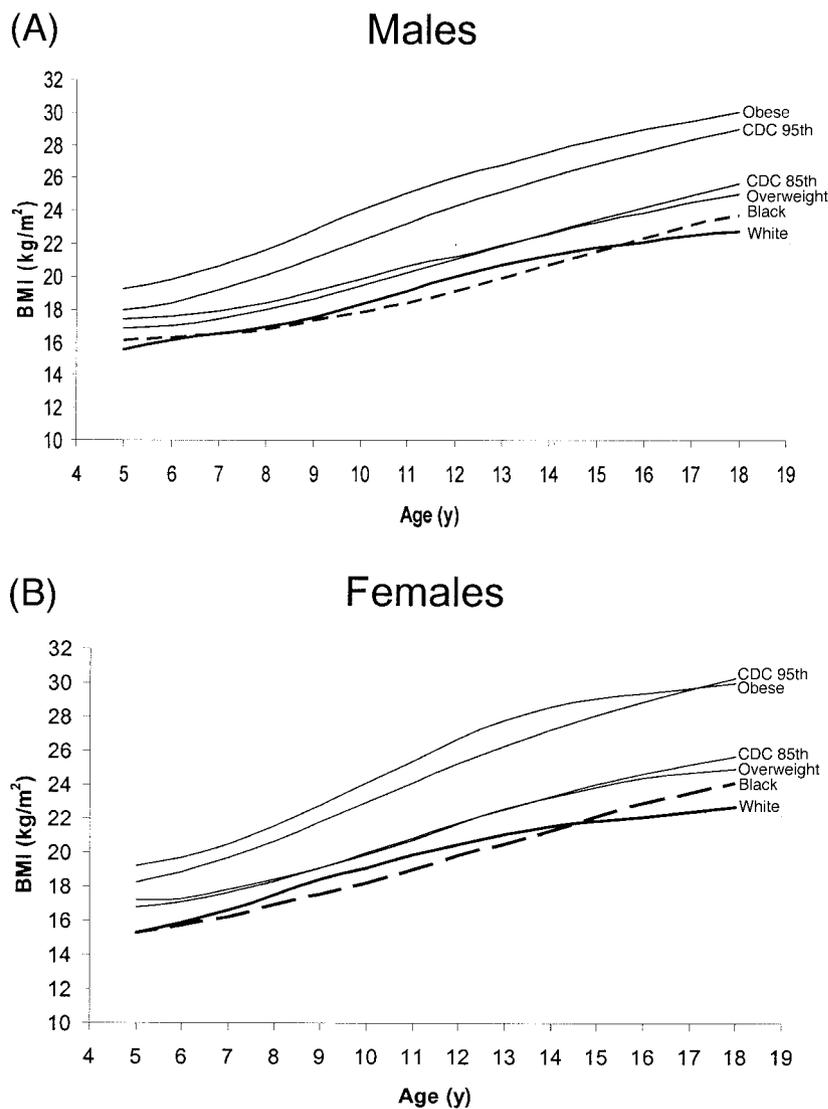


Fig 3. Comparison of BMI thresholds from the Bogalusa Heart Study (1992-1994) with the international reference cutoff values for defining overweight and obesity⁹ and the US CDC 85th and 95th percentiles²⁰ for male (A) and female (B) subjects.

TABLE 4. Comparison of Sensitivity and Specificity of BMI Thresholds Derived in the Current Study, International Overweight and Obesity Cutoff Values, and US CDC 85th and 95th Percentiles for Identifying Risk Factor Clustering Among 5- to 18-Year-Old Children and Adolescents in the Bogalusa Heart Study (1992-1994)

BMI Cutoff	Current Study		Overweight*		Obesity*		CDC 85th†		CDC 95th†	
	Se	Sp	Se	Sp	Se	Sp	Se	Sp	Se	Sp
White male	83.7	63.6	69.6	76.8	45.2	93.7	71.9	75.1	57.8	89.3
Black male	73.9	56.4	63.6	79.6	30.7	93.6	63.6	77.7	45.5	90.1
White female	82.7	66.8	70.1	75.8	37.8	93.6	73.2	75.9	44.1	91.2
Black female	74.7	60.1	65.3	74.3	43.2	92.3	63.2	74.1	46.3	88.7
Entire sample	79.6	62.4	67.6	76.5	39.8	93.4	68.8	75.7	49.0	89.9

Se indicates sensitivity (%); Sp, specificity (%).

* International overweight and obesity cutoff values.⁹

† US CDC 85th and 95th percentiles.²⁰

that study and the current study support the idea that waist circumference can be used effectively to evaluate clinically the presence or absence of elevated cardiovascular disease risk factors among children and adolescents.

The results of this community-based study extend those of previous analyses that examined associations between waist circumference and cardiovascular disease risk factors among children,^{21,38-40} by presenting health-related BMI and waist circumference

thresholds. The study by Flodmark et al³⁸ showed that waist circumference was significantly correlated with atherogenic risk factors in a sample of obese Swedish children, and a previous analysis of the Bogalusa Heart Study cohort used in the present study demonstrated significant correlations between waist circumference and cardiovascular disease risk factor levels.²¹ Furthermore, waist circumference was a better predictor of cardiovascular disease risk factors than was BMI for a sample of 10- to 14-year-

old children from Cyprus; those with a waist circumference above the 75th percentile had significantly higher odds of having high blood pressure, high total cholesterol levels, high low-density lipoprotein cholesterol levels, and high triglyceride levels.³⁹ Finally, in a sample of prepubertal (3–11 years of age) Italian children, those with waist circumferences greater than the 90th percentile were more likely (19%) to have multiple risk factors (≥ 2), compared with children with values below the 90th percentile (9.4%).⁴⁰ Therefore, there is consistent evidence that waist circumference is related to cardiovascular disease risk factors and risk factor clustering among children and youths.

Because risk factors clusters tend to be stable traits that track well from childhood into adulthood, perhaps even better than individual risk factors,^{18,19} it can be hypothesized that BMI and waist circumference in childhood may predict adulthood disease outcomes. This has been demonstrated for the BMI,^{41–43} but data for waist circumference are apparently lacking. The association between childhood waist circumference and adulthood disease cannot be addressed with the current study design; however, future research should be focused on identifying waist circumference thresholds in childhood that predict adult health outcomes.

The Bogalusa Heart Study involves a well-characterized sample of children and adolescents from a biracial population in Louisiana. The results of this study demonstrate the utility of BMI and waist circumference in the prediction of risk factor clustering in this sample. Additional work in other populations is required to determine the generalizability of these thresholds. Given the increases in the prevalence of obesity among children and adolescents that have occurred in the past few decades⁴⁴ and the associated increases in health care costs,⁴⁵ the inclusion of anthropometric measures of obesity, such as BMI and waist circumference, in periodic medical examinations is warranted.

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