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BMI percentiles for the identification of abdominal obesity and metabolic risk in children and adolescents: Evidence in support of the CDC 95th percentile

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Abstract

Objectives—BMI percentiles have been routinely and historically used to identify elevated adiposity. This paper aimed to investigate the optimal Centers for Disease Control and Prevention (CDC) body mass index (BMI) percentile that predicts elevated visceral adipose tissue (VAT), fat mass and cardiometabolic risk in a biracial sample of children and adolescents.

Participants and Methods—This cross-sectional analysis included 369 white and African American children (5–18 y). BMI was calculated using height and weight and converted to BMI percentiles based on CDC growth charts. Receiver operating characteristic curve analysis identified the optimal (balance of sensitivity and specificity) BMI percentile to predict the upper quartile of age-adjusted VAT (measured by magnetic resonance imaging), age-adjusted fat mass (measured by dual energy x-ray absorptiometry) and elevated cardiometabolic risk (≥ 2 of high glucose, triglycerides and blood pressure and low high density lipoprotein cholesterol) for each race-by-sex group.

Results—The optimal CDC BMI percentile to predict those in the top quartile of age-adjusted VAT, age-adjusted fat mass and elevated cardiometabolic risk were the 96th, the 96th and the 94th percentiles, respectively, for the sample as a whole. Sensitivity and specificity was satisfactory (> 0.70) for VAT and fat mass. Compared to age-adjusted VAT and age-adjusted fat mass, there was a lower overall accuracy of the optimal percentile in identifying those with elevated cardiometabolic risk.

Conclusions—The present findings support the utility of the 95th CDC BMI percentile as a useful threshold for the prediction of elevated levels of VAT, fat mass and cardiometabolic risk in children and adolescents.

The study is registered at clinicaltrials.gov as NCT01595100.

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Keywords

body mass index; visceral adipose tissue; children; adolescents; Centers for Disease Control and Prevention; body fat

Introduction

Body mass index (BMI) is routinely used in surveillance and as a screening tool to identify those with excess adiposity.¹ In children, the absolute BMI is typically not utilized as a marker of risk because the measures which constitute BMI (weight and height) change as a function of normal growth and maturation. Therefore, it is important that BMI is adjusted for age or that the BMI of children of the same age and sex are compared.² Age- and sex-specific BMI percentiles, such as those based on the U.S. Centers for Disease Control and Prevention (CDC) growth reference curves,³ are typically used for the identification of obesity-related health risks in children and adolescents. According to these reference data, for children and adolescents aged 2–19 y, a BMI between the 85th and 94th (inclusive) percentiles places them in the overweight category, while those 95th percentile are classified as obese.⁴

While the CDC percentiles are commonly used, their utility is understudied. Several studies have investigated the health implications of being 85th and 95th percentiles,^{5, 6} while others have aimed to identify an optimal age-specific BMI or BMI percentile to predict children at elevated cardiovascular risk.^{7–11} Studies in diverse pediatric samples are required to further delineate the optimal BMI percentiles to identify high levels of total and abdominal adiposity and associated health risk and whether the 95th CDC percentile is indeed a useful cut-off in diverse samples. The aim of this study was to investigate the optimal CDC BMI percentile that predicts higher visceral adipose tissue (VAT), total body fat mass and cardiometabolic risk in a biracial sample of children and adolescents.

Participants and Methods

Sample

Originally, 423 participants were enrolled in a cross-sectional study of factors related to abdominal adiposity in the Baton Rouge, Louisiana area. Recruitment occurred through radio and television advertisements and through pediatrician's offices. Recruitment aimed to have balanced numbers across sex, race (white and African American [AA]), and BMI categories (normal weight, overweight and obese). Participants self-reported their race (from six options offered) and sex. Thirteen were excluded from the present analysis as their self-reported race was not white or AA, 40 were excluded for missing key variables (magnetic resonance imaging scans = 26, blood chemistry = 12 and dual energy X-ray absorptiometry = 2) and 1 was excluded due to being an outlier (VAT >3 standard deviations above the group mean). Those who were missing data were significantly younger (11.0 vs. 12.3 y; $P < 0.01$), had a higher BMI (25.2 vs. 23.1; $P < 0.04$) than those with full data while there was no difference in BMI percentile (80th vs. 73rd; $P = 0.55$). The current analysis included 369 participants (94 white males, 79 AA males, 83 white females and 113 AA females). Parents/

guardians provided signed informed consent, and the children provided written assent. This study complies with the Declaration of Helsinki and all study procedures were approved by the Pennington Biomedical Research Center Institutional Review Board.

Body Mass Index (BMI)

Height and weight were measured by staff trained in anthropometry. Height was measured twice to the nearest 0.1 cm using a wall-mounted stadiometer after the participant removed their shoes. Weight was measured twice to the nearest 0.1 kg using a digital scale with the participant wearing only light clothes and shoes were removed. The mean of the two heights and the mean of the two weights were used in analyses (closest two of three if the first two measurements were greater than 0.5 cm or 0.5 kg apart, respectively). BMI was calculated as weight (kg)/height (m²) with age- and sex-specific BMI percentiles calculated using the SAS program for the 2000 CDC Growth Charts for the United States.¹²

Visceral Adipose Tissue (VAT)

VAT volumes were calculated from magnetic resonance imaging (MRI) scans which were performed using a General Electric Signa Excite (3.0 Tesla; GE Medical Systems, Milwaukee, WI) scanner. Participants lay motionless on the scanner table and an 8 channel torso-array coil was placed over their chest/abdomen area. Slice images were analyzed using the Analyze (CNSoftware, Rochester, MN) software package with each analyzed slice being 4.78 cm apart. VAT area was manually drawn by one trained technician and the number of pixels was multiplied by voxel width and height for each slice to compute VAT area (cm²). The area from each slice was multiplied by the slice gap (28 slices), then multiplied by 0.000001 (to convert to l) and multiplied by the voxel depth. The 5 to 8 slice volumes were summed to calculate total volume of VAT in liters for each participant.

Total Body Fat Mass

A whole body dual energy X-ray absorptiometry (DXA) scanner (Hologic QDR 4500, Bedford, MA) was used to quantify participant's total body fat mass. Participants lay motionless on the scan table in light clothes and no metal containing objects, while a scanner emitting low energy X-rays passed over the body. All scans were analyzed with QDR for Windows V.11.2 and total fat mass was calculated.

Cardiometabolic Risk Factors

Blood pressure was measured using a mercury manometer following 5 minutes of quiet seated rest. Measurements were taken twice with a third taken if the first two measures differed by 10 mm/Hg. Blood samples were obtained following an overnight fast. Serum triglycerides, high density lipoprotein cholesterol (HDL-C) and glucose concentrations were obtained from a Beckman Coulter DXC 600 (Brea, CA), with reagents from Beckman Coulter and Trinity (Fisher Scientific, Pittsburg, PA).

Cardiometabolic risk factors were defined as follows:¹³ HDL-C 45 mg/dL or triglycerides 75 mg/dL (in 5–9 year-olds) or 90 mg/dL (in 10–18 year-olds); fasting blood glucose 100 mg/dL (for mmol/L, multiply the mg/dL value by 0.02586); and high blood pressure if systolic or diastolic blood pressure 90th percentile for age, sex and height. Participants with

2 cardiometabolic risk factors were considered to have elevated cardiometabolic risk. Waist circumference (WC) was not used as a risk factor in the definition of elevated cardiometabolic risk due to its high correlation with BMI ($r = 0.96$ in the present analysis).

Statistical Analysis

As age was significantly correlated with both VAT ($r = 0.31$; $P < 0.001$) and fat mass ($r = 0.39$; $P < 0.001$), VAT and fat mass were regressed on age in each race-by-sex group and the unstandardized residuals were retained to represent age-adjusted VAT and age-adjusted fat mass. In the absence of an absolute level of VAT and fat mass that has been shown to be detrimental to health in the pediatric age range, the top quartile of each race-by-sex group was used to represent a negative health outcome. The upper quartile of the residual age-adjusted VAT corresponded to > 0.028 , > 0.024 , > 0.065 and $> 0.042 \text{ cm}^2$ for white males, AA males, white females and AA females, respectively. The upper quartile of the residual age-adjusted fat mass corresponded to > 5.31 , > 6.68 , > 8.48 and $> 7.82 \text{ kg}$ for white males, AA males, white females and AA females, respectively.

Receiver operating characteristic (ROC) curve analysis was undertaken to identify the optimal BMI percentile (defined as the percentile which maximized both sensitivity and specificity) to predict the upper quartile of age-adjusted VAT, age-adjusted fat mass and elevated cardiometabolic risk. The area under the curve (AUC) was calculated to express how close the ROC curve was to a test of perfect sensitivity and specificity (an AUC of 1.0)¹⁴ with an AUC of 0.5 meaning the criteria is no better than the flip of a coin. The criteria of Swets (1988) were used to assess the accuracy of the sensitivity and specificity values.¹⁵ Differences between groups were assessed using one-way analysis of variance and chi-square test. All analyses were undertaken using IBM SPSS V.20 (IBM Corp, Armonk, NY).

Results

The characteristics of each race-by-sex group are presented in Table 1 stratified by age groups. The mean age of the sample was 12.3 y (range 5.1 – 18.9 y). The mean CDC BMI percentile was 70 (± 27), 76 (± 27) and 70 (± 29) for age groups 5–9, 10–14 and 15–18 years, respectively. Prevalence of obesity (BMI \geq CDC 95th percentile) was 26.6%, 32.0%, 20.5% and 47.8% for white and AA males and white and AA females, respectively. Differences between age-groups within each race-by-sex group are also highlighted in Table 1.

Table 2 presents the proportion of participants with each risk factor partitioned by whether they had fewer than 2 risk factors ($n=319$; 86.5%) or ≥ 2 risk factors ($n=50$; 13.5%). The variables most consistently contributing to the ≥ 2 risk factors were high TG and low HDL-C in each race-by-sex group.

Tables 3 – 5 present the optimal CDC BMI percentiles and related values. For age-adjusted VAT (Table 3), all AUCs were high (> 0.93) with sensitivity and specificity equally satisfactory (i.e. > 0.70) in all groups.¹⁵ The optimal age- and sex-specific CDC BMI percentiles ranged from the 89th to 97th. For age-adjusted fat mass (Table 4), all AUCs were

0.97 with excellent sensitivity and specificity. The optimal age- and sex-specific CDC BMI percentiles ranged from the 89th to 98th. For 2 cardiometabolic risk factors (Table 5), all AUCs, except for AA females, were significantly greater than an AUC of 0.5, but accuracy was considered low with an AUC < 0.70 in the whole group and for white males and AA females. The optimal age- and sex-specific CDC BMI percentile ranged from the 84th to 97th. Figure 1 is a graphical representation of the AUCs for the whole sample. Compared to age-adjusted VAT and age-adjusted fat mass, the AUC for 2 cardiometabolic risk factors was lower (0.68). The optimal age- and sex-specific CDC BMI percentile to predict those in the top quartile of age-adjusted VAT, age-adjusted fat mass and elevated cardiometabolic risk were the 96th, 96th and 94th percentiles, respectively, for the sample as a whole.

Discussion

BMI percentiles are widely used to classify children as overweight or obese with the overall objective of identifying children at higher health risk. The utility of these percentiles to identify those with higher levels of risk is not well studied. This analysis adds to the extant literature by identifying an optimal CDC BMI percentile that differentiates those with higher levels of VAT and total fat mass and elevated cardiometabolic risk in a biracial pediatric sample. The optimal CDC BMI percentiles ranged from the 94th and 96th CDC percentiles for the sample as a whole. While the AUCs for both VAT and fat mass were excellent, the AUC for cardiometabolic risk factors would be deemed low. Nonetheless, given the present results and its historical use as a definition of obesity, the CDC 95th percentile would seem to satisfactorily identify these children and adolescents at higher health risk.

The purpose of the 95th BMI percentile as the cutoff for surveillance and screening is to capture risk associated with high levels of adiposity while minimizing over- and under-diagnosis.⁴ From the present results, using the 96th CDC percentile in this whole sample (Table 3), 90% of children would be correctly classified as being in the top quartile of fat mass, while 11% would be incorrectly classified as being in the top quartile of fat mass. Increasing the percentile cut-off would result in less children being correctly identified as having high fat mass but false positives would be reduced also. Studies examining the performance of BMI percentiles for identifying excess body fat are hampered by the lack of consistent definitions of excess body fat in children⁴ and performance depends on the definition of excess adiposity and the criterion that is used.^{16, 17} Studies have used various cutoffs including the 85th, 90th or 95th body fat percentiles of a population sample^{5, 18–22} or percent body fat criteria.²³ Using the definition of excess adiposity as the 90th percentile of age-adjusted sum of skinfolds, only 65% of children at the 95th CDC BMI percentile had excess adiposity in a study of 6731 children aged 5 – 17 y.⁵ When defining obesity as 25% body fat for boys and 30% body fat for girls,²⁴ Sardinha et al found that the CDC BMI percentiles of 63rd – 90th for boys and 75th – 81st percentiles for girls provided the best sensitivity and specificity for identifying those who are obese.²³ The present study used the gold standard measures of DXA to assess total body fat mass with the top quartile used as an estimation of excess adiposity. Body fat percentiles/reference data have been proposed based on skinfold thickness and bioelectrical impedance,^{25, 26} but unless a specific threshold

of body fat is associated with negative health outcomes, body fat reference data serve as a normative reference standard and a means of ranking children against their peers.

While studies have correlated BMI to VAT in children, little is known about the performance of BMI percentiles in predicting depot-specific adiposity. A small sample of obese females with a BMI 95th percentile (10 – 16 y, 93% white,) had a mean level of VAT equivalent to 0.137 l.⁶ Furthermore, the authors reported that obese (BMI 95th percentile) females had significantly more VAT versus normal weight females.⁶ While VAT has been related to negative health outcomes,⁶ a VAT threshold that differentiates those at high risk from those at low risk has not been identified in children. The present study used the top quartile of VAT and, using the 96th CDC percentile, 87% of children would be correctly classified as being in the top quartile of VAT while 13% would be incorrectly classified as being in the top quartile of VAT. While not a measure of central adiposity *per se*, BMI is just as related to VAT as WC is in adults²⁷ and children.^{28–30}

If BMI can perform as well as body fat to predict health risk³¹ then it would be prudent to relate BMI directly to health risk, thus circumnavigating the translation of BMI to risk via body fat. Freedman et al found that 39% of children 95th BMI percentile had 2 risk factors, while the 99th percentile had a higher predictive value for the presence of risk factors.⁵ Caprio et al. reported that adolescent girls 95th BMI percentile had unfavorable lipids, blood pressure and insulin compared to their counterparts at the 50th percentile.⁶ While the 94th CDC percentile was identified as optimal for the sample as a whole in the present study (Table 5), the predictive capability is limited (34% not identified as having 2 risk factors and 32% incorrectly classified as having 2 risk factors). This represents a lower overall accuracy of the optimal BMI percentile. However, while these children 95th CDC percentile may not have the pathology of the cardiometabolic risk factors, they are likely to have higher VAT and/or high total adiposity (87% – 90% sensitivity in Tables 3 and 4) and so could be identified using the percentile criterion before the manifestation of risk. Furthermore, for children < 85th percentile, BMI is more highly correlated with fat-free mass than with fat mass³² so BMI must be used cautiously in normal weight children.

Compared to the present findings, other studies have reported lower sensitivity and higher specificity for the CDC 85th and 95th BMI percentiles in predicting excess adiposity and risk factors, particularly in females.^{9, 16, 17, 23, 33} A test with low sensitivity and high specificity is a test which minimizes false positives to the detriment of misclassifying those at risk. The use of the 95th CDC percentile should be viewed in this context. When selecting an appropriate threshold for risk classification it is important to assess the benefits resulting from a correct outcome and any potential costs associated with false positives and negatives.^{14, 15} A conservative approach whereby false positives are minimized must be balanced with the larger level of false negatives.²³

Longitudinally, BMI percentiles during childhood have value in predicting obesity in adulthood.⁵ Children 95th percentile had higher odds of being overweight/obese at age 35 years.^{34, 35} However, using ROC analysis, the cutpoint which maximized sensitivity and specificity was found to be the 60th percentile (NHANES II, 1976–1980) at 18 y with excellent predictive capability compared to BMI percentiles in younger age groups.³⁴ Sun et

al. (2008) found that the CDC 75th and 60th percentiles for boys and girls, respectively, identified those who later developed metabolic syndrome in middle age.³⁶ Further research is needed to disentangle how BMI percentiles in childhood can be used as an indicator of future health.

The strengths of this study include the biracial sample which spans 5 – 18 y and the gold standard measurements of body fatness. Limitations include the low prevalence of cardiometabolic risk in each race-by-sex group. Given the low AUCs for 2 cardiometabolic risk factors, future studies should include larger samples if possible. Due to race differences in risk factor prevalence,³⁷ and visceral³⁸ and total adiposity³⁹ in children, it is prudent to examine multi-racial samples. Having a wide variation of BMI across age groups was a component of the recruitment design so the prevalence of obesity for the sample is higher than the value of 18.2% from a recent representative US sample,⁴⁰ thus the optimal percentile may be different in a representative sample.¹⁵ This analysis was not powered to stratify by race, sex and age group. However, results of the ROC analysis stratified by age group (5–9, 10–14 and 15–18 years) revealed similar AUCs, sensitivity and specificity and optimal CDC BMI percentiles (data not shown). In the absence of a level of VAT and total body fat mass that differentiates those with and without health risk, the present analysis used the top quartile of age-adjusted VAT and fat mass to represent a higher level of risk. The optimal BMI percentile may differ depending on the value of the top quartile or if the top tertile was used. However, when divided into tertiles, the optimal BMI percentiles to predict the top tertile of age-adjusted total body fat mass were between the 90th and 97th (results not shown). More research is needed to determine if the sample-specific level of age-adjusted VAT and fat mass reported in this study are indeed related to current and future health.

This is among the first studies that have investigated BMI percentiles as they relate to VAT, fat mass and cardiometabolic risk factors. While WC and BMI are equally correlated with VAT in a pediatric population, BMI has been routinely and historically used, and many data exist for comparison purposes. Identifying a BMI percentile which could be used to identify children of different ethnicities who have relatively elevated levels of VAT, fat mass and metabolic risk will add to the usefulness of BMI for clinicians and researchers. The present findings support the utility of the CDC 95th BMI percentile as a sensible and useful threshold for the prediction of relatively high VAT mass, fat mass and cardiovascular risk.

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Novelty/Impact

Using gold standard measures and a sample that spans a large age and BMI range, this study determines optimal CDC BMI percentiles which predict higher visceral adiposity, fat mass and cardiovascular risk in a bi-racial sample. The results lend credence to the 95th CDC percentile.

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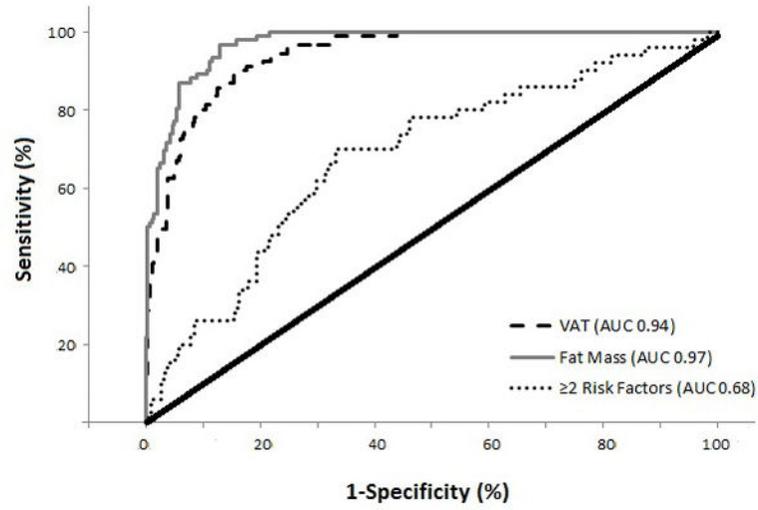


Figure 1. ROC curves for CDC BMI percentiles in the prediction of upper quartile of age-adjusted VAT, upper quartile of age-adjusted fat mass and ≥ 2 cardiometabolic risk factors in the whole sample

Table 1

Participant characteristics

	Age Group, y	BMI, kg/m ²	VAT, l	Fat Mass, kg	Obese*, %
White Males	5-9 (n=23)	17.2 (2.6) ^a	0.06 (0.05) ^a	6.7 (3.67) ^{ab}	13.0
	10-14 (n=45)	21.8 (4.5) ^a	0.16 (0.17)	14.2 (8.5) ^a	28.9
	15-18 (n=26)	25.6 (6.4) ^a	0.27 (0.25) ^a	19.5 (13.1) ^b	34.6
AA Males	5-9 (n=21)	19.5 (5.8) ^a	0.07 (0.09) ^a	8.6 (7.5) ^{ab}	23.8
	10-14 (n=41)	23.0 (6.2)	0.11 (0.12)	15.2 (10.9) ^a	36.6
	15-18 (n=17)	26.4 (5.8) ^a	0.17 (0.14) ^a	18.3 (10.3) ^b	35.3
White Females	5-9 (n=21)	19.3 (4.7) ^{ab}	0.11 (0.10)	11.2 (7.9) ^{ab}	23.8
	10-14 (n=41)	22.7 (5.3) ^a	0.18 (0.15)	19.2 (9.6) ^a	24.4
	15-18 (n=21)	23.2 (4.8) ^b	0.17 (0.14)	18.7 (7.9) ^b	9.5
AA Females	5-9 (n=33)	20.5 (5.8) ^{ab}	0.08 (0.07) ^{ab}	11.7 (8.0) ^{ab}	42.4
	10-14 (n=49)	26.9 (7.5) ^a	0.17 (0.14) ^a	23.9 (13.0) ^a	61.2 ^a
	15-18 (n=31)	28.0 (8.2) ^b	0.18 (0.14) ^b	27.0 (16.3) ^b	32.3 ^a

Note:

* CDC 95th percentile ³. AA - African American. Values are presented as mean (standard deviation) unless indicated. Values with the same superscript letter are significantly different within race-by-sex group, $P < 0.05$.

Table 2
Percentage of participants with each of the cardiometabolic risk factors partitioned by risk factor classification

	< 2 risk factors				2 risk factors			
	White Male (n=77)	AA Male (n=71)	White Female (n=69)	AA Female (n=102)	White Male (n=17)	AA Male (n=8)	White Female (n=14)	AA Female (n=11)
High blood pressure (%)	3.9	5.6	0.0	5.9	17.6	25.0	14.3	36.4
High Glucose (%)	0.0	2.8	1.4	3.9	17.6	12.5	7.1	18.2
High triglycerides (%)	20.8	4.2	29.0	6.9	88.2	75.0	100	81.8
Low HDL-C (%)	24.7	16.9	11.6	9.8	88.2	87.5	85.7	72.7

Note: HDL-C - high density lipoprotein cholesterol

Results of ROC analysis for the optimal CDC BMI percentile for predicting the upper quartile of age-adjusted VAT for the whole sample and for each race-by-sex group

Table 3

	AUC*	Optimal BMI Percentile	Sensitivity (%)	Specificity (%)
All (n=369)	0.94 [0.92–0.96]	96	87	87
White Males (n=94)	0.97 [0.94–0.99]	93	87	89
AA Males (n=79)	0.97 [0.93–1.0]	96	95	90
White Females (n=83)	0.95 [0.91–0.99]	89	91	87
AA Females (n=113)	0.93 [0.89–0.98]	97	86	82

Note: Values in closed brackets are 95% confidence intervals; AA indicates African American; AUC indicates area under the curve; BMI indicates body mass index

* all AUCs are significant at $P < 0.001$

Results of ROC analysis for the optimal CDC BMI percentile for predicting the upper quartile of age-adjusted total body fat mass for the whole sample and for each race-by-sex group

Table 4

	AUC*	Optimal BMI Percentile	Sensitivity (%)	Specificity (%)
All (n=369)	0.97 [0.95–0.98]	96	90	89
White Males (n=94)	0.98 [0.96–1.0]	94	100	97
AA Males (n=79)	0.99 [0.99–1.0]	97	100	98
White Females (n=83)	0.98 [0.96–1.0]	89	100	90
AA Females (n=113)	0.98 [0.96–1.0]	98	93	93

Note: Values in closed brackets are 95% confidence intervals; AA indicates African American; AUC indicates area under the curve; BMI indicates body mass index.

* all AUC are significant at $P < 0.001$

Table 5

Results of ROC analysis for the optimal CDC BMI percentile for predicting 2 cardiometabolic risk factors for the whole sample and each race-by-sex group

	AUC	Optimal BMI Percentile	Sensitivity (%)	Specificity (%)
All (n=369)	0.68 [0.60–0.76]**	94	66	68
White Males (n=94)	0.68 [0.52–0.83]*	84	71	68
AA Males (n=79)	0.73 [0.51–0.95]*	97	75	80
White Females (n=83)	0.78 [0.64–0.92]*	94	79	81
AA Females (n=113)	0.65 [0.48–0.81]	97	64	62

Note: Values in closed brackets are 95% confidence intervals; AA indicates African American; AUC indicates area under the curve; BMI indicates body mass index.

** $P < 0.001$;

* $P < 0.05$