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Cardio-metabolic risk screening among adolescents: Understanding the utility of body mass index, waist circumference, and waist to height ratio

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Abstract

Background—Few studies have assessed how well BMI, waist circumference (WC), or waist to height ratio (WtHR) perform in identifying cardio-metabolic risk among youth.

Objective—To evaluate the utility of BMI and WC percentiles and WtHR to distinguish adolescents with and without cardio-metabolic risk.

Methods—A cross-sectional analysis of data from 6097 adolescents ages 10-13 who participated in the HEALTHY study was conducted. Receiver operating characteristic curves determined the discriminatory ability of BMI and WC percentiles and WtHR.

Results—The discriminatory ability of BMI percentile was good (Area Under the Curve (AUC) ≥ 0.80) for elevated insulin and clustering of ≥3 risk factors, with optimal cut points of 96 and 95 respectively. BMI percentile performed poor to fair (AUC = 0.57 to 0.75) in identifying youth with the majority of individual risk factors examined (elevated glucose, total cholesterol, low-density lipoprotein, blood pressure, triglycerides, and high-density lipoprotein). WC percentile and WtHR performed similarly to BMI percentile.

Conclusions—The current definition of obesity among US children performs well at identifying adolescents with elevated insulin and a clustering of ≥ 3 cardio-metabolic risk factors. Evidence

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does not support WC percentile or WtHR as superior screening tools compared to BMI percentile for identifying cardio-metabolic risk.

Keywords

adolescents; cardiovascular risk; body mass index; screening; waist circumference

Introduction

Accurate identification of youth at increased risk for cardiovascular disease and metabolic disorders is critical for prevention and intervention efforts. As measuring a youth's height and weight is a simple procedure, body mass index (BMI) is the most commonly used surrogate measure of adiposity and screening tool for cardio-metabolic risk.[1] In the United States, the cut points of ≥ 85th and ≥ 95th percentiles of age- and gender-specific BMI of the 2000 CDC growth charts[2] are the recommended and standard definitions of overweight and obesity, respectively, among children and adolescents.[1]

Although cardio-metabolic risk is positively correlated with BMI percentile,[3-5] there is a paucity of research evaluating the usefulness of BMI percentile as a screening tool to identify cardiometabolically at-risk adolescents. Among the small number of studies that have aimed to address this knowledge gap, methodological approaches vary and results are mixed. Two studies have observed that BMI percentile cut points ranging between 50 and 57 best distinguish adolescents who exhibit clustering of cardio-metabolic risk factors.[6,7] However, these studies utilized cut points for cardio-metabolic risk internal to the study sample, not the currently-recommended definitions of elevated risk. This approach limits the external validity of study findings. In contrast, using externally-recommended cut points, Ice et al.[8] observed that the 95th percentile was optimal at identifying adolescents with 3 or more cardiovascular risk factors among a primarily Caucasian sample of early adolescents, while Lee et al.[9] found that BMI percentile performed poorly in identifying elevated triglycerides and high-density lipoprotein (HDL) among children participating in NHANES 1999-2004. Given the inconsistency in the definition of elevated cardio-metabolic risk and the limited number of studies with diverse study samples, further research is needed to characterize the performance of BMI percentile as a screening tool for cardio-metabolic risk among adolescents. Further, studies are needed to test the utility of the 85th and 95th BMI percentiles in discriminating youth with and without elevated cardio-metabolic risk.

It has also been suggested that waist circumference (WC) and waist to height ratio (WtHR) may be superior screening methods with which to identify children at high risk for cardio-metabolic outcomes compared to BMI percentile, in part because of their ability to assess central adiposity.[10-14] Studies frequently identify children with a WC ≥ the 75th percentile or 90th percentile utilizing standardized percentiles[11] or a WtHR > 0.50 as having excess adiposity.[15] However, little research has been conducted to evaluate the discriminatory ability of WC or WtHR to identify youth with elevated cardio-metabolic risk.

Given the limited testing of the utility of BMI percentile, WC percentile, and WtHR as population-based screening tools for cardio-metabolic risk among adolescents, research is needed to ensure that there are evidence-based standards with which to identify children at greatest risk. Therefore, the goal of the present study was to utilize data from the multi-ethnic cohort of over 6,000 young adolescents who participated in the HEALTHY study[16] to determine the utility of BMI percentile, WC percentile, and WtHR as screening tools and identify the optimal cut points of these measures for distinguishing adolescents with poor cardio-metabolic profiles.

Methods

Study Design

Data were drawn from the baseline sample of participants in the HEALTHY study, a 3-year cluster randomized controlled trial to prevent the development of risk factors for type 2 diabetes in a high risk group of middle school-aged children. Details of the HEALTHY intervention and study protocol have been published elsewhere.[16] For HEALTHY, 7 participating centers recruited 42 US middle schools with student populations at increased risk for type 2 diabetes, i.e., with at least 50% of students eligible for free or reduced-price lunch or belonging to a racial or ethnic minority group. Sixth-grade students in each school were invited to health screenings in the fall of 2006; 57.6% of students agreed and were enrolled in the study. There was little difference in the mean age, mean BMI percentile, racial distribution, or gender distribution between eligible students who did and did not enroll in the study.[17] The study was approved by the sites' Institutional Review Boards, and parent consent and child assent were obtained. For the current study, students between the ages of 10 and 13 and who had complete measurements (n=6097) were included in the analysis. This sample represents 95.9% of the total baseline study sample (n=6358). Subjects excluded did not significantly differ from the analytic sample on any demographic characteristics or mean BMI percentile.

Measures

Assessment methods have been reported in detail previously.[16] Height and weight were measured by trained, certified study staff using the Prospective Enterprises PE-AIM-101 stadiometer and the SECA Corporation α 882 electronic scale. BMI percentile for age and sex was calculated using the Centers for Disease Control and Prevention 2000 reference charts.[2] A Gulick tape was used to measure waist circumference on bare skin measured just above the iliac crest. Age and gender-specific waist circumference percentiles were calculated using the LMS method values from NHANES III (1988-94) calculated by Cook, et al.[18] WtHR was calculated as waist in cm/height in cm. Blood was drawn from fasted students to assess metabolic (glucose, insulin) and cardiovascular (total cholesterol, low-density lipoprotein (LDL), HDL, triglycerides) risk factors, and analyzed by the Northwest Lipid Metabolism and Diabetes Research Laboratories, University of Washington, Seattle. Blood pressure was recorded 3 times using an automated blood pressure monitor (Omron HEM-907 or HEM-907XL, Vernon Hills, IL), and the mean of the second and third recordings was used for analysis.

Elevated levels of each of the cardio-metabolic risk factors were selected based on recommended definitions for adolescents identified in the literature. Elevated fasting glucose was defined by a level of ≥ 100 mg/dL, as recommended by the American Diabetes

Association[19] and elevated insulin was defined by a level of ≥ 30 μU/mL, as previously used in the HEALTHY study.[20] Blood pressure percentiles were determined using the National Heart Lung and Blood Institute guidelines and adjusted for age, sex and height percentile,[21] with elevated risk classified as systolic (SBP) or diastolic blood pressure (DBP) at or above the 95th percentile. This definition is consistent with the definition of hypertension recommended by the Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents Summary Report.[22] Abnormal lipid levels were defined by the "high" cut points as described by the Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents Summary Report[22] [total cholesterol ≥200 mg/dL, LDL ≥130 mg/dL, triglycerides ≥ 130 mg/dL, and HDL ≤40 mg/dL]. Variables indicating an accumulation of elevated risk factors (≥ 1, ≥2, and ≥3), out of the 7 possible risk factors, were also created.

Pubertal status was self-reported using the Pubertal Development Scale[23] and converted to the pubertal stage groups outlined by Tanner.[24] Ethnicity and race were self-reported by students. Students checking "Hispanic or Latino" were classified as Hispanic, non-Hispanics choosing only "Black or African American" race were classified as Black, non-Hispanics choosing only "White" race were classified as White; all other response categories were combined into "Other." A parent or guardian reported the highest level of household education.

Statistical Analysis

All statistical analyses were performed using SAS 9.2 (SAS Institute Inc, Cary, NC). Characteristics of the sample were summarized using means, standard deviations, and percents. Receiver Operating Characteristics (ROC) curve analyses were performed using continuous measures of BMI and WC percentile and WtHR to identify optimal cut points to predict children with elevated cardio-metabolic risk for each value of the entire distribution. Sensitivity (true-positive rate), specificity (true-negative rate), and positive and negative predictive values (PPV and NPV) for predicting cardio-metabolic risk at each BMI and WC percentile and WtHR value were calculated. Optimal cut points were obtained from the Youden index [maximum (sensitivity + specificity - 1)]. Greater accuracy is reflected by a larger Youden index.[25] The standard logistic regression model in SAS and the trapezoidal rule method were used to compute the Area Under the Curve (AUC) and its associated 95% CI for each cardio-metabolic risk factor. Differences in AUC were examined as a function of gender, three racial/ethnic groups (Hispanics, Blacks, and Whites), and six gender by race/ethnicity group combinations. A 1-degree of freedom chi-square test was used to compare the AUCs under the independent ROC curves between the gender and race/ethnicity groups, and between the gender-race combinations. AUC for the "Other" race group was not specifically computed due to heterogeneity of this group. Differences in AUCs for the risk factors of insulin and HDL were also examined by Tanner stage and tested using a 1-degree of freedom chi-square test due to evidence that insulin resistance and HDL vary due to maturation.[26] A 1-degree of freedom chi-square test was also used to compare the AUCs for BMI percentile, WC percentile, and WtHR for each outcome. When examining gender and race differences and differences in AUCs across BMI percentile, WC percentile, and WtHR, only p-values ≤0.01 were considered to be statistically significant.

Results

Demographic characteristics and mean levels of cardio-metabolic risk factors for participants in the current analyses (n=6097) are presented in Table 1. For all of the cardio-metabolic risk factors examined, the proportion of adolescents with elevated risk and a clustering of risk factors increased as BMI percentile and WtHR increased (all $p \leq 0.01$ from test of trend). Significant positive associations were also observed between WC percentile and all of the cardio-metabolic risk factors with $p \leq 0.01$ except cholesterol (p=0.10) and LDL (p=0.03) (Table 2).

Performance of BMI percentile as a method to identify at-risk adolescents

For the outcomes of glucose, blood pressure, total cholesterol, and LDL, BMI percentile performed poorly in distinguishing adolescents at elevated health risk with AUCs below 0.70 (Table 3). BMI percentile was a fair measure with which to identify adolescents with elevated triglycerides (AUC=0.74) and low HDL (AUC=0.75). For the outcome of elevated insulin, BMI percentile performed in the good range (AUC = 0.87). Examining the clustering of risk factors, BMI percentile performed in the fair range at distinguishing youth with ≥1 and ≥2 risk factors, while the AUC was in the good range (0.80) for identification of youth with ≥3 risk factors. For all but one of the outcomes examined, the presence of at least one cardio-metabolic risk factor, no differences in the performance of BMI percentile were observed by race/ethnicity or gender. BMI percentile was a better tool with which to identify the presence of at least one cardio-metabolic risk factor among Hispanic versus Black youth, with AUCs of 0.72 and 0.66, respectively (p=0.003). No significant differences were observed in the ability of BMI to predict elevated insulin by Tanner stage. However, BMI had a lower predictive ability for HDL for youth in Tanner stage 1 versus 2 and 3, although the AUCs were all in the poor to fair range (Stage 1 = 0.68, Stage 2 = 0.77, Stage 3 = 0.76, all $p \leq 0.01$).

The only individual cardio-metabolic risk factor for which BMI percentile had good discriminatory ability (AUC ≥ 0.80) was elevated insulin, with an optimal BMI percentile cut point of 96. Using a BMI percentile cut point of 96, 82.8% of youth were accurately identified as having elevated insulin (sensitivity) and 78.2% of youth without elevated insulin were accurately identified (specificity). The NPV was high, 98.4%, therefore the risk of having elevated insulin is very low for youth with a BMI percentile less than 96. However, the PPV observed for the 96^{th} percentile was low indicating a high proportion of false positive findings, with only 21.6% of youth who screen positive having elevated insulin. The optimal cut point to identify youth with an accumulation of 3 or more risk factors was 95, the current cut point for obesity among youth, with corresponding sensitivity and specificity of 73.4 and 73.6 and an NPV of 97.5, but a low PPV of 16.4.

Performance of WC percentile and WtHR as methods to identify at-risk adolescents

WC percentile performed similarly to BMI percentile in its ability to distinguish youth with elevated cardio-metabolic risk factors; no statistically significant differences in AUCs were observed for WC percentile and BMI percentile. As with BMI percentile, WC percentile performed well at identifying youth with elevated insulin (AUC = 0.87) and ≥3 risk factors

(AUC = 0.80). The optimal WC percentile to identify youth with elevated insulin was 92 and the optimal WC percentile to identify youth with ≥3 risk factors was 85. WtHR performed similarly to BMI and WC for all outcomes except insulin, for which the AUC for WtHR was significantly lower than that for WC (0.83 vs. 0.87, p=0.003). Insulin was the only risk factor for which WtHR performed well at identifying risk, with an optimal WtHR of 0.54 (Table 4).

Similar to BMI percentile, neither gender nor race/ethnicity significantly affected the ability of WC percentile or WtHR to distinguish adolescents at elevated risk for nearly all risk factors examined. WC percentile and WtHR were both significantly less accurate for distinguishing the presence of at least one risk factor among Black youth as compared to Hispanic youth. For WC the AUC was 0.64 for Black youth and 0.72 for Hispanic youth (p = 0.0003) and for WtHR the AUC was 0.66 for Black youth and 0.72 for Hispanic youth (p=0.0007).

The discriminatory ability of WC among overweight youth was also examined for all of the cardio-metabolic outcomes with the goal of determining whether combining these measures in sequence may produce greater insight into cardio-metabolic risk among adolescents not identified as obese by BMI percentile. Discriminatory ability of WC among overweight adolescents was poor, with AUCs ranging from 0.47 to 0.66.

Discussion

Accurate yet low-burden methods to screen for elevated cardio-metabolic risk among adolescents may be useful for monitoring and intervention activities that are focused on reducing the likelihood of progression of chronic disease in adulthood. Consistent with previous research, current findings indicate that cardio-metabolic risk increases with BMI percentile, WC percentile, and WtHR. However, these screening tools only had good predictive value in identifying children with elevated insulin, with BMI and WC percentiles also accurately distinguishing youth with 3 or more risk factors. Optimal BMI percentile cut points were 96 to identify elevated insulin and 95 to identify 3 or more risk factors, corresponding to the current BMI percentile cut point for obesity among children. Few differences in the utility of BMI or WC percentiles or WtHR as screening tools were observed by race/ethnicity or gender, despite research identifying varying levels of cardiovascular risk within a given weight status across genders and racial/ethnic groups.[27]

Findings that BMI percentile had relatively poor predictive ability for individual elevated cardio-metabolic risk factors, with the exception of insulin, are consistent with the study conducted by Lee et al.[9] In a recent study by Garnett, et al.,[28] fasting insulin, but not fasting glucose, performed well at identifying youth who were insulin resistant as determined by an oral glucose tolerance test. Therefore, being able to adequately screen for elevated insulin with BMI percentile is important for efforts to identify youth in need of intervention to prevent type II diabetes. Compared to the findings for individual risk factors, BMI percentile performed better in distinguishing adolescents who exhibited a clustering of 3 or more cardio-metabolic risk factors. As the clustering of cardio-metabolic risk factors has been found to be a fairly stable trait between adolescence and adulthood,[29] knowledge that a BMI percentile of 95 consistently performs well in identifying adolescents with a clustering of 3 or more risk factors, each defined by external standards, is clinically useful. Further, given that the NPV for the cut point of 95 was very high (97.5), there is a low likelihood that using the 95th percentile to identify adolescents with elevated cardio-metabolic risk will miss a significant proportion of those who do have a clustering of risk factors.

The discriminatory ability of WC percentile and WtHR largely mirrored that of BMI percentile. Further, WC demonstrated low ability to identify youth with elevated cardio-metabolic risk factors among those who were overweight. Together these data suggest that use of WC percentile or WtHR as alternatives to BMI percentile, or WC percentile in combination with BMI percentile, does not offer an advantage in identifying adolescents with elevated cardio-metabolic risk.

There are a number of strengths of the current study including its utilization of external cut points for elevated cardio-metabolic risk that reflect current recommendations in clinical practice. To our knowledge, this is the first study to assess the discriminatory ability of WC percentile characterized as a continuous variable. This allowed for identification of the optimal cut points of 85 for ≥3 risk factors and 92 for elevated insulin, which serves as an important addition to prior literature that identified that cardio-metabolic risk was higher among youth with WCs between the 75th and 90th percentiles.[11] Finally, use of a study sample specifically recruited to represent low-income and racial and ethnic minority students allowed for examination of the utility of BMI and WC percentiles and WtHR a screening tools among populations at high risk for obesity and adiposity-related health outcomes. However, as the PPV of a screening test is affected by the prevalence of the health outcomes in the study population, recruitment of study schools with populations at high risk for cardio-metabolic risk factors may have yielded an elevated PPV.

The current definition of obesity among adolescents performed well in identifying youth with elevated insulin and a clustering of 3 or more risk factors, but only poor to fair in identifying other individual cardio-metabolic risk factors. These findings suggest that use of the distinction of obese versus not obese may be useful for distinguishing adolescents in need of additional cardio-metabolic diagnostic testing and intervention. WC percentile and WtHR did not provide superior identification of high cardio-metabolic risk as compared to BMI, and WC among overweight adolescents did not provide additional benefits for identifying youth with elevated risk. However, as the current study assessed the utility of BMI, WC, and WtHR to distinguish adolescents with concurrent cardio-metabolic risk, longitudinal studies are needed to identify the extent to which these measures are useful in identifying future cardio-metabolic risk.

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What is already known about this subject

- Currently in the United States, the 85th and 95th percentiles of age- and gender-adjusted body mass index (BMI) are used to define overweight and obesity among youth.
- Few studies have evaluated how well BMI percentile cut points, or alternatively waist circumference or waist to height ratio cut points, distinguish youth with and without cardio-metabolic risk.

What This Study Adds

- Among a multi-ethnic population of US adolescents, BMI percentiles of 96 and 95 worked well at identifying youth with elevated insulin and a clustering of 3 or more risk factors.
- Waist circumference percentile nor waist to height ratio provided superior screening ability for cardio-metabolic risk factors as compared to BMI percentile.

Table 1

Demographic characteristics and cardio-metabolic risk among adolescent participants in the HEALTHY study

	Overall (n=6097)	Male (n=2902)	Female (n=3195)
Age, %			
10 years	2.0	1.9	2.2
11 years	68.3	64.5	71.8
12 years	25.6	28.9	22.6
13 years	4.1	4.8	3.4
Tanner stage, %			
1	10.2	15.2	5.6
2	25.7	40.0	12.8
3	40.4	38.1	42.6
4	21.6	6.5	35.3
5	2.1	0.3	3.7
Race/ethnicity, %			
Hispanic	53.2	52.6	53.7
Non-Hispanic Black	19.6	19.1	20.1
Non-Hispanic White	18.9	20.4	17.5
Other	8.3	7.9	8.7
Highest education level attained by head of household, %			
Less than high school	12.5	12.3	12.7
Some high school	14.7	14.2	15.1
High school graduate	25.0	24.3	25.7
Some college or specialized training	28.8	29.6	28.1
College or university graduate	13.3	13.9	12.7
Postgraduate training or degree	5.7	5.8	5.7
Body Mass Index (BMI), mean (SD)	22.3 (5.4)	22.4 (5.5)	22.2 (5.4)
Weight status, %			
Underweight (BMI percentile <5)	1.5	1.6	1.4
Normal weight (BMI percentile 5-84)	49.2	46.4	51.8
Overweight (BMI percentile 85-94)	19.7	18.9	20.4
Obese (BMI percentile ≥95)	29.5	33.1	26.3
Waist circumference (WC), cm, mean (SD)	75.7 (15.0)	75.9 (16.0)	75.5 (14.0)
Waist to Height (WtHR) ratio, mean (SD)	0.50 (0.09)	0.50 (0.10)	0.50 (0.08)
Glucose, mg/dL, mean (SD)	93.4 (6.7)	94.3 (6.6)	92.6 (6.7)
Insulin, μU/mL, mean (SD)	13.3 (11.6)	12.2 (12.0)	14.3 (11.0)
Systolic Blood Pressure, mmHg, mean (SD)	107.5 (10.1)	108.3 (10.3)	106.8 (9.8)
Diastolic Blood Pressure, mmHg, mean (SD)	63.7 (8.8)	63.5 (8.9)	63.9 (8.7)
Total Cholesterol, mg/dL, mean (SD)	157.2 (27.3)	159.0 (28.0)	155.6 (26.5)
Low-Density Lipoprotein, mg/dL, mean (SD)	87.0 (23.3)	88.5 (23.7)	85.5 (22.8)
High-Density Lipoprotein, mg/dL, mean (SD)	52.7 (12.3)	53.1 (12.6)	52.3 (12.0)
Triglycerides, mg/dL, mean (SD)	88.0 (51.1)	86.8 (51.1)	89.0 (51.1)

	Overall (n=6097)	Male (n=2902)	Female (n=3195)
Clustering of cardio-metabolic risk factors, %			
≥ 1	45.8	48.0	43.8
≥ 2	18.7	20.4	17.1
≥ 3	6.6	7.5	5.8

Table 2

Frequency of elevated cardio-metabolic risk factors by body mass index (BMI) percentile, waist circumference (WC) percentile, and waist to height ratio (WtHR) category among participants in the HEALTHY study (n=6097).

	Glucose	Insulin	Blood Pressure*	Total Cholesterol	Low-Density Lipoprotein	High-Density Lipoprotein	Triglycerides	≥ 1 risk factor	≥ 2 risk factors	≥ 3 risk factors
BMI percentile										
<5th	10.8	0.0	7.5	6.5	2.2	2.2	2.2	26.9	3.2	1.1
5th-79th	13.7	0.8	7.5	4.5	2.8	5.8	4.8	31.3	7.3	1.2
80th-84th	11.9	1.3	5.0	5.0	3.1	9.7	12.6	34.6	10.1	4.1
85th-89th	13.8	2.6	5.5	6.3	4.4	14.0	12.0	39.1	14.8	3.9
90th-94th	16.8	3.4	8.1	7.5	5.8	16.0	19.2	50.0	19.2	5.8
≥ 95th	20.8	19.4	15.4	9.3	6.8	32.2	29.1	70.3	38.8	16.4
WC percentile										
< 5th	11.1	1.6	9.0	7.4	3.7	0.0	2.1	26.5	5.8	2.1
5th-74th	13.5	0.8	7.3	4.7	2.8	6.2	5.3	31.4	7.6	1.4
75th-79th	14.0	1.4	9.2	7.2	3.8	11.3	11.0	42.8	13.0	2.1
80th-84th	17.0	2.1	6.4	4.8	3.9	16.1	13.9	44.2	15.5	4.5
85th-89th	18.8	4.2	9.2	9.4	7.2	17.5	22.3	54.5	23.6	7.7
90th -94th	19.5	7.4	10.5	9.7	7.4	24.3	25.9	59.6	29.2	12.1
≥95th	20.5	26.6	16.5	8.2	6.3	37.8	32.5	76.1	43.8	19.1
WtHR										
<0.40	10.4	0.6	8.8	5.0	2.0	3.2	1.6	26.5	4.6	0.6
0.40-<0.45	13.0	0.6	7.2	4.4	2.8	4.3	3.9	28.7	6.5	1.0
0.45-<0.50	14.6	1.6	7.2	5.3	2.8	10.2	9.1	38.0	10.4	2.0
0.50-<0.55	18.2	4.0	8.9	6.6	5.4	17.5	17.4	49.9	20.1	6.7
0.55-<0.60	20.6	9.6	10.4	11.5	9.1	27.5	29.7	65.0	34.1	13.6
0.60-<0.65	20.3	21.8	15.8	8.6	5.8	38.4	33.0	76.9	42.3	16.8
≥0.65	21.6	38.8	20.6	9.0	7.2	40.4	36.2	81.7	51.9	26.5

*Percentage reported is for total blood pressure

Table 3

Results of ROC curve analysis to identify optimal BMI percentile to predict cardio-metabolic risk, and performance of existing overweight and obesity cut points among participants in the HEALTHY study (n=6097).

	AUC* (95% CI)	BMI percentile†	Sensitivity	Specificity	PPV	NPV
Glucose	0.57 (0.55, 0.59)	85	57.4	52.3	18.7	86.5
		92	**47.4**	**64.1**	**20.2**	**86.4**
		95	38.2	72.1	20.8	85.9
Total Cholesterol	0.59 (0.56, 0.62)	85	63.6	51.8	8.4	95.3
		91	**54.8**	**61.1**	**8.9**	**95.1**
		95	42.2	71.4	9.3	94.7
Low-Density Lipoprotein	0.62 (0.59, 0.65)	85	68.3	51.6	6.2	97.2
		86	**67.5**	**53.3**	**6.3**	**97.2**
		95	45.0	71.2	6.8	96.5
Blood Pressure	0.60 (0.58, 0.63)	85	61.8	52.1	12.1	92.8
		95	47.3	72.4	15.4	92.8
		96	**44.4**	**76.1**	**16.5**	**92.8**
Triglycerides	0.74 (0.72, 0.76)	85	80.8	56.2	24.0	94.5
		89	**76.5**	**62.3**	**25.8**	**93.9**
		95	58.6	75.5	29.1	91.4
High-Density Lipoprotein	0.75 (0.73, 0.76)	85	80.1	56.5	25.4	93.9
		92	**69.7**	**68.2**	**28.9**	**92.4**
		95	60.9	76.3	32.2	91.3
Insulin	0.87 (0.85, 0.88)	85	93.9	54.0	12.9	99.2
		95	85.0	74.5	19.4	98.6
		96	**82.8**	**78.2**	**21.6**	**98.4**
≥1 Risk Factor	0.70 (0.68, 0.71)	85	65.0	64.1	60.5	68.5
		91	**56.9**	**74.5**	**65.4**	**67.2**
		95	45.3	83.8	70.3	64.5
≥2 Risk Factors	0.75 (0.74, 0.77)	85	79.8	57.8	30.3	92.6
		91	**72.2**	**67.5**	**33.8**	**91.4**
		95	61.3	77.8	38.8	89.7
≥3 Risk Factors	0.80 (0.78, 0.82)	85	88.6	53.5	11.9	98.5
		95	**73.4**	**73.6**	**16.4**	**97.5**

*AUC was computed over the entire range of specificity and sensitivity values and evaluated using the trapezoidal rule method

†For each cardio-metabolic risk, select results are presented in the table, though each BMI percentile across the entire distribution was evaluated. Specifically, results shown represent the optimal BMI percentile cut point (as identified by Youden index and denoted in bold) and the two common thresholds for overweight (85th percentile) and obesity (95th percentile) status.

Table 4

Results of ROC curve analysis to identify optimal waist circumference (WC) percentile and waist to height ratio (WtHR) predict cardio-metabolic risk, and performance of recommended WC percentile cut points among participants in the HEALTHY study (n=6097).

	Waist Circumference Percentile						Waist to Height Ratio					
	AUC* (95% CI)	**WC %ile†**	**Sens.**	**Spec.**	**PPV**	**NPV**	**AUC* (95% CI)**	**WtHR**	**Sens.**	**Spec.**	**PPV**	**NPV**
Glucose	0.57 (0.55, 0.59)	75	56.4	53.9	19.0	86.6	0.57 (0.55, 0.59)	**0.52**	**47.0**	**65.0**	**20.4**	**86.5**
		78	**54.2**	**57.0**	**19.4**	**86.7**						
		90	37.7	71.4	20.1	85.7						
Total Cholesterol	0.57 (0.54, 0.60)	75	60.9	53.2	8.3	95.1	0.59 (0.56, 0.62)	**0.50**	**59.7**	**56.3**	**8.6**	**95.3**
		87	**49.0**	**66.1**	**9.1**	**94.9**						
		90	40.7	70.7	8.8	94.5						
Low-Density Lipoprotein	0.61 (0.57, 0.64)	75	66.4	53.1	6.2	97.1	0.62 (0.58, 0.65)	**0.50**	**65.0**	**56.2**	**6.5**	**97.2**
		87	**55.0**	**66.0**	**7.0**	**96.9**						
		90	45.4	70.7	6.7	96.5						
Blood Pressure	0.59 (0.56, 0.61)	75	59.9	53.5	12.1	92.6	0.56 (0.54, 0.59)	**0.54**	**40.5**	**71.7**	**12.3**	**92.4**
		90	44.5	71.5	14.2	92.4						
		92	**41.5**	**75.5**	**15.2**	**92.4**						
Triglycerides	0.75 (0.74, 0.77)	75	81.8	58.1	25.1	94.9	0.75 (0.73, 0.77)	**0.52**	**72.1**	**68.9**	**27.6**	**93.7**
		83	**75.8**	**66.1**	**27.7**	**94.1**						
		90	61.7	75.4	30.0	92.0						
High-Density Lipoprotein	0.76 (0.75, 0.78)	75	80.5	58.3	26.3	94.2	0.75 (0.73, 0.76)	**0.52**	**69.2**	**68.7**	**27.8**	**92.8**
		87	**69.1**	**71.4**	**30.9**	**92.6**						
		90	63.0	76.1	32.8	91.7						
Insulin	0.87 (0.86, 0.89)	75	93.4	55.6	13.2	99.2	0.83 (0.80, 0.85)	**0.54**	**80.6**	**73.3**	**13.7**	**98.6**
		90	86.2	74.0	19.4	98.7						
		92	**83.0**	**78.0**	**21.4**	**98.4**						
≥1 Risk Factor	0.70 (0.69, 0.71)	75	64.5	66.4	61.9	68.9	0.69 (0.67, 0.70)	**0.52**	**53.0**	**76.1**	**64.3**	**66.6**
		83	**57.3**	**74.6**	**65.6**	**67.4**						
		90	45.9	83.3	69.9	64.6						
≥2 Risk Factors	0.75 (0.74, 0.77)	75	78.9	59.4	30.9	92.5	0.74 (0.72, 0.76)	**0.52**	**68.7**	**69.8**	**32.5**	**91.3**
		86	**70.2**	**71.6**	**36.2**	**91.3**						

	Waist Circumference Percentile						Waist to Height Ratio					
	AUC* **(95% CI)**	**WC %ile†**	**Sens.**	**Spec.**	**PPV**	**NPV**	**AUC*** **(95% CI)**	**WtHR**	**Sens.**	**Spec.**	**PPV**	**NPV**
		90	61.6	77.2	38.3	89.8						
≥3 Risk Factors	0.80 (0.78, 0.82)	75	88.6	55.1	12.3	98.6	0.78 (0.76, 0.81)	**0.52**	**80.0**	**65.7**	**12.3**	**98.2**
		85	**83.4**	**65.7**	**14.7**	**98.2**						
		90	74.7	73.1	16.4	97.6						

*The AUC was computed over the entire range of specificity and sensitivity values and evaluated using the trapezoidal rule method

†For each cardio-metabolic risk factor, select results are presented in the table, though each WC percentile and WtHR across the entire distribution was evaluated. Specifically, results shown represent the optimal WC percentile and WtHR cut point (as identified by Youden index and denoted in bold) and the two common thresholds for high WC (75^{th} and 90^{th} percentile).