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Original Article

BMI-Specific Waist Circumference Thresholds to Discriminate Elevated Cardiometabolic Risk in White and African American Adults

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Key Words

Waist circumference · Obesity · Risk factors · Epidemiology

Abstract

Objective: Waist circumference (WC) is a useful anthropometric tool to estimate cardiometabolic risk. However, BMI influences the relationship between WC and health. This study determined BMI-, sex- and race-specific WC thresholds. ***Methods:*** The study sample included 6,452 whites and African Americans (AA) aged 18–64 years. WC, BMI, and cardiovascular risk factors were assessed in the clinic. An elevated cardiometabolic risk was defined as the presence of ≥2 cardiometabolic risk factors. Receiver Operating Characteristic (ROC) curves were used to determine BMI-, sex-, and race-specific WC thresholds. ***Results:*** Based on logistic regression, elevated WC within each BMI category was associated with higher cardiometabolic risk. The respective optimal BMI-specific WC thresholds for white women, AA women, white men, and AA men were as follows: 72, 76, 82, and 78 cm for normal-weight (18.5–24.9 kg/m^2); 87, 85, 95, and 92 cm for overweight (25–29.9 kg/m^2); 97, 97, 107, and 104 cm for obese I (30–34.9 kg/m^2); and 111, 110, 120, and 119 cm for obese II+ (≥35 kg/m^2) participants. Sensitivities ranged from 52.7 to 73.3%, and specificities ranged from 57.1 to 73.5%. ***Conclusion:*** The proposed optimal BMI-, sex-, and race-specific WC thresholds are warranted for use in the clinical setting until representative standards become available based on results from longitudinal studies.

Introduction

Anthropometric surrogates of adiposity are important clinical tools to predict deleterious health consequences [1]. Waist circumference (WC) provides a simple anthropometric measurement that is a significant predictor of both total body fat and abdominal visceral fat [2]. Even within BMI categories, elevated WC is associated with increased cardiometabolic

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risk [3] and premature mortality [4]. In clinical practice, measuring WC in addition to BMI is recommended by the National Institutes of Health / National Heart, Lung, and Blood Institute [5] and the National Cholesterol Education Program Adult Treatment Panel III [6].

Establishing WC thresholds within each BMI category improves the prediction of cardiometabolic health risk [7]. Additionally, demographic variables including sex and race affect the relationship between WC and health outcomes, so their inclusion is warranted in WC thresholds [1]. Current guidelines recommend a single WC threshold in men and in women regardless of BMI [8]. Because the recommended WC thresholds do not take into consideration BMI category or race, there is an urgent need for the development of BMI-specific cutoffs for WC including sex- and race-specific values [1]. The purpose of this study was to develop BMI-, sex-, and race-specific WC thresholds in a sample of white and African American men and women.

Participants and Methods

Participants

The study sample included 6,452 adults (2,087 white women, 1,782 African American women, 1,944 white men, and 639 African American men) aged 18–64 years from the Pennington Center Longitudinal Study (PCLS). The PCLS is an ongoing investigation of the relationship between obesity, lifestyle factors, and chronic disease, including baseline data collected from volunteer participants in a variety of research projects conducted at Pennington Biomedical Research Center (PBRC) in Baton Rouge, LA, between the years 1992 and 2011. Participants were recruited from the greater Baton Rouge area through the local media and web-based advertisements. Race was self-reported as white or African American, based on investigator-defined options. The study was approved by the PBRC Institutional Review Board, and participants gave informed consent. Participants with complete data, including anthropometry, cardiometabolic risk factor measurements, and covariates, were retained for the present analysis.

Anthropometry

The full methodology of PCLS has been previously reported [9]. In brief, height was the average of two measurements (the closest two of three if difference exceeded 0.5 cm) obtained using a stadiometer. Weight was the average of two measurements (the closest two of three if difference exceeded 0.5 kg) obtained on a digital scale. BMI was calculated as the ratio of weight (kg) divided by height in m^2. WC was measured using an inelastic tape measure positioned at the midpoint between the superior aspect of the iliac crest and the inferior border of the ribcage, with the average of two measurements (three if difference exceeded 0.5 cm) used in analysis.

Cardiometabolic Risk

Blood pressure measurements were obtained using a stethoscope and standard sphygmomanometer, or a validated Omron automatic measuring device, following 5 min of rest during which participants were in a semirecumbent position in a quiet room. Participants were asked to refrain from vigorous exercise, food or caffeine ingestion, and smoking for 30 min prior to measurement. The average of two blood pressure measurements was used in analysis. A fasting blood lipid and glucose panel was obtained after a 12-hour fast which provided serum triglycerides, high-density lipoprotein (HDL) cholesterol, and plasma glucose analyzed on a Beckman Coulter Chemistry Analyzer (Beckman Coulter, Brea, CA, USA). Participants were asked to refrain from vigorous exercise and alcohol consumption 24 h prior to the blood draw.

Participants were classified as having elevated cardiometabolic risk with ≥2 risk factors from the following: blood pressure ≥ 130 mm Hg for systolic or ≥ 85 mm Hg for diastolic (or reported treated hypertension); glucose ≥ 5.55 mmol/l (or diagnosed with diabetes); triglycerides ≥ 1.695 mmol/l; or HDL cholesterol < 1.036 mmol/l for men or < 1.295 mmol/l for women.

Covariates

Age (calculated from birth and observation dates), smoking status (nonsmokers, current smokers, or former smokers), and menopausal status (premenopausal or postmenopausal) were determined by self-report and used as covariates in the analysis.

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Statistical Analysis

Participants were categorized based on BMI: normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), obese I (30–34.9 kg/m^2), or obese II+ (≥35 kg/m^2). Logistic regression analysis was used to compute the odds ratios (ORs) of elevated cardiometabolic risk per standard deviation of WC within each BMI category, stratified by sex and race. Age, smoking status, and menopausal status (for women) were included in the models as covariates. Receiver Operating Characteristic (ROC) curves were used to determine the utility of WC to discriminate the presence of ≥2 risk factors within each BMI category, stratified by sex and race. Optimal WC thresholds to determine elevated cardiometabolic risk were selected within each sex-by-race group based on the convergence of the sensitivity (true-positive) and specificity (true-negative) rates. The sensitivities and specificities for these BMI-specific WC thresholds were compared to the sensitivities and specificities of the current NIH guidelines of 88 cm for women and 102 cm for men [5]. Logistic regression analyses were conducted using SAS version 9.2, and ROC analyses were conducted using PASW version 19.

Results

Descriptive characteristics of the study sample are reported in table 1, stratified by BMI category, sex, and race. Participants' mean (± SD) age was 38.9 ± 12.9 years. A fraction of the participants reported having diabetes (n = 687) and hypertension (n = 736). WC increased across increasing BMI categories in each sex-by-race group, averaging 75.7 ± 7.2 cm in normal-weight, 89.1 ± 8.2 cm in overweight, 100.7 ± 8.9 cm in obese I, and 114.2 ± 11.9 cm in obese II+ categories. Across increasing BMI categories, the prevalence of elevated individual risk factors and the presence of ≥2 cardiometabolic risk factors increased. Elevated cardiometabolic risk occurred in 12.0% of normal-weight adults, 29.4% of overweight adults, 47.2% of obese I adults, and 60.2% of obese II+ adults.

Logistic regression analyses indicated that within each BMI category, the OR of having ≥2 cardiometabolic risk factors was significantly higher at higher WC levels in all sex-by-race groups (table 2). ORs for ≥2 cardiometabolic risk factors across sex-by-race groups ranged from 1.5 to 3.6 in normal-weight adults, from 1.3 to 1.6 in overweight adults, from 1.4 to 1.9 in obese I adults, and from 1.1 to 1.7 in obese II+ adults. In African American women and African American men of normal BMI, a 1 SD difference in WC (5.7 cm) was associated with 3.6 and 3.4 greater ORs of having ≥ 2 cardiometabolic risk factors, respectively.

The area under the curve (AUC) for the utility of WC to discriminate elevated cardiometabolic risk in each sex-by-race group was significantly > 0.05, ranging from 0.663 to 0.839 in normal-weight adults, from 0.659 to 0.686 in overweight adults, from 0.627 to 0.687 in obese I adults, and from 0.557 to 0.664 in obese II+ adults. The one exception was for white men in the obese II+ category, with an AUC of 0.557 (95% CI 0.485–0.628). As depicted in table 3, the optimal BMI-specific WC thresholds were as follows: in the normal-weight group, 72.1 cm in white women, 76.2 cm in African American women, 82.1 cm in white men, and 78.3 cm in African American men; in the overweight group, 86.6 cm in white women, 85.3 cm in African American women, 94.5 cm in white men, and 91.8 cm in African American men; in the obese I group, 96.8 cm in white women, 96.6 cm in African American women, 107.0 cm in white men, and 104.3 cm in African American men; and in the obese II+ group, 110.6 cm in white women, 109.9 cm in African American women, 120.1 cm in white men, and 118.8 cm in African American men. Table 4 presents the WC thresholds, rounded to the nearest cm, to facilitate clinical use. Sensitivities ranged from 52.7 to 73.3%, and specificities ranged from 57.1 to 73.5%.

Compared to the currently recommended single WC thresholds, the BMI-specific WC thresholds had higher sensitivities for normal-weight and overweight adults across sex-by-race groups (range 57.7–73.3% vs. 0–53.8%) but lower specificities for these BMI groups (range 57.8–73.5% vs. 70–100%). In contrast, for the obese I and obese II+ groups, the BMI-specific WC thresholds had higher specificities (range 57.1–64.4% vs. 0–43.8%) and lower sensitivities (range 57.3–64.4% vs. 68.3–100%) compared to the current guidelines.

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Table 1. Characteristics of the sample[a]

	White					African American				
	normal	overweight	obese I	obese II+	p value	normal	overweight	obese I	obese II+	p value
Women, n	547	625	494	421		211	434	536	601	
Age, years	36.9 (13.9)	42.7 (12.5)	44.6 (11.2)	44.0 (11.6)	<0.0001	32.3 (11.3)	38.0 (12.1)	39.9 (11.5)	41.3 (11.1)	<0.0001
WC, cm	72.1 (6.2)	85.7 (7.1)	96.6 (7.7)	112.3 (10.8)	<0.0001	73.2 (5.7)	85.0 (6.6)	96.7 (8.0)	110.8 (11.4)	<0.0001
High blood pressure, %	11.9	23.5	27.9	48.0	<0.0001	14.7	30.7	40.5	55.4	<0.0001
High blood glucose, %	11.7	26.7	39.3	53.4	<0.0001	9.5	25.4	41.4	51.9	<0.0001
High triglycerides, %	10.1	26.7	35.2	45.4	<0.0001	1.9	8.8	14.4	13.3	<0.0001
Low HDL-cholesterol, %	19.6	29.1	40.9	54.2	<0.0001	19.9	24.9	34.7	39.9	<0.0001
≥2 risk factors, %	9.5	27.4	43.7	63.0	<0.0001	7.1	23.7	41.2	52.4	<0.0001
Men, n	453	685	529	277		141	193	194	111	
Age, years	29.3 (11.4)	37.0 (13.4)	41.5 (12.4)	41.5 (11.6)	<0.0001	27.2 (8.7)	35.5 (12.3)	37.6 (12.4)	38.7 (12.5)	<0.0001
WC, cm	81.0 (6.2)	94.5 (7.3)	107.5 (6.8)	122.2 (10.1)	<0.0001	76.7 (5.7)	90.6 (6.5)	103.8 (6.9)	120.4 (11.2)	<0.0001
High blood pressure, %	15.9	27.0	41.8	56.3	<0.0001	17.7	32.6	45.9	60.4	<0.0001
High blood glucose, %	22.3	38.0	49.9	63.2	<0.0001	17.0	32.6	44.3	55.0	<0.0001
High triglycerides, %	9.7	32.3	49.2	56.7	<0.0001	2.8	10.4	19.1	25.2	<0.0001
Low HDL-cholesterol, %	23.4	28.2	39.9	50.2	<0.0001	14.9	17.6	24.7	33.3	0.0014
≥2 risk factors, %	17.7	36.2	58.2	72.6	<0.0001	10.6	24.9	42.3	61.3	<0.0001

[a]Mean values with standard deviation indicated in parentheses. P value indicates significant difference in elevated risk across BMI category, based on analysis of variance (for continuous variables) or chi square test of proportion (for categorical variables).

Table 2. Logistic regression analysis discriminating the odds of elevated risk factor and odds of ≥2 cardiometabolic risk factors per standard deviation increase in waist circumference[a]

	White				African American			
	normal	overweight	obese I	obese II+	normal	overweight	obese I	obese II+
Women								
High blood pressure	0.8 (0.6–1.0)	1.2 (1.0–1.5)	1.4 (1.1–1.7)	1.3 (1.1–1.6)	1.5 (1.0–2.3)	1.2 (1.0–1.6)	1.3 (1.1–1.6)	1.3 (1.1–1.6)
High blood glucose	1.4 (1.1–1.8)	1.7 (1.4–2.0)	2.0 (1.6–2.5)	1.6 (1.3–2.0)	2.3 (1.3–4.1)	1.5 (1.1–1.9)	1.9 (1.5–2.4)	1.8 (1.4–2.2)
High triglycerides	1.3 (1.0–1.8)	1.5 (1.2–1.8)	1.5 (1.2–1.8)	1.2 (1.0–1.5)	1.1 (0.4–3.0)	1.5 (1.1–2.1)	1.5 (1.2–2.0)	1.3 (1.0–1.7)
Low HDL-cholesterol	1.2 (1.0–1.5)	1.3 (1.1–1.6)	1.4 (1.2–1.7)	1.3 (1.0–1.6)	1.4 (1.0–2.0)	1.2 (1.0–1.6)	1.4 (1.1–1.6)	1.2 (1.0–1.4)
≥2 risk factors	1.5 (1.1–1.9)	1.6 (1.3–2.0)	1.9 (1.6–2.4)	1.7 (1.4–2.2)	3.6 (1.7–7.8)	1.5 (1.1–1.9)	1.8 (1.5–2.3)	1.6 (1.3–1.9)
Men								
High blood pressure	1.4 (1.0–1.9)	1.4 (1.1–1.7)	1.4 (1.1–1.7)	1.1 (0.9–1.5)	1.8 (1.1–2.8)	1.0 (0.7–1.5)	1.0 (0.7–1.4)	1.0 (0.7–1.7)
High blood glucose	1.3 (1.0–1.7)	1.2 (1.0–1.5)	1.2 (1.0–1.5)	1.1 (0.9–1.5)	2.1 (1.3–3.5)	1.9 (1.2–3.0)	1.4 (1.0–2.0)	1.1 (0.7–1.7)
High triglycerides	2.2 (1.5–3.2)	1.7 (1.4–2.1)	1.2 (1.0–1.5)	0.9 (0.7–1.2)	3.0 (1.2–7.8)	1.5 (0.8–2.6)	1.2 (0.8–1.7)	1.1 (0.7–1.7)
Low HDL-cholesterol	1.8 (1.4–2.3)	1.4 (1.1–1.7)	1.2 (1.0–1.5)	1.0 (0.8–1.3)	1.7 (1.0–2.7)	1.2 (0.7–1.9)	1.4 (1.0–2.0)	1.6 (1.0–2.5)
≥2 risk factors	1.8 (1.4–2.5)	1.6 (1.3–2.0)	1.4 (1.2–1.7)	1.1 (0.9–1.5)	3.4 (1.8–6.5)	1.3 (0.8–2.0)	1.3 (0.9–1.8)	1.4 (0.9–2.2)

[a]Odds ratios with 95% CIs indicated in parentheses. Models control for age, smoking status, and menopausal status (for women).

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Table 3. Receiver operating characteristic analysis for the utility of waist circumference in discriminating the presence of ≥2 cardiometabolic risk factors

	Area under the curve	95% CI	Optimal threshold	Sensitivity, %	Specificity, %
Normal weight					
White women	0.663	(0.590–0.736)	72.1	57.7	57.8
AA women*	0.839	(0.740–0.938)	76.2	73.3	73.5
White men	0.681	(0.616–0.747)	82.1	62.5	62.2
AA men	0.828	(0.741–0.916)	78.3	73.3	73.0
Overweight					
White women	0.659	(0.611–0.706)	86.6	62.6	62.1
AA women	0.660	(0.601–0.718)	85.3	59.2	59.5
White men	0.683	(0.582–0.678)	94.5	63.3	63.4
AA men	0.686	(0.596–0.777)	91.8	62.5	63.4
Obese I					
White women	0.684	(0.637–0.731)	96.8	64.4	64.4
AA women	0.687	(0.641–0.732)	96.6	62.4	63.5
White men	0.630	(0.582–0.678)	107.0	60.1	58.8
AA men	0.627	(0.548–0.706)	104.3	57.3	57.1
Obese II+					
White women	0.662	(0.611–0.714)	110.6	61.5	60.9
AA women	0.664	(0.621–0.708)	109.9	62.5	62.2
White men	0.557	(0.485–0.628)	120.1	52.7	52.6
AA men	0.661	(0.557–0.764)	118.8	60.3	60.5

*AA indicates African American.

Discussion

The purpose of this study was to determine BMI-, sex-, and race-specific WC thresholds to discriminate elevated cardiometabolic risk among white and African American men and women in PCLS. BMI alone was associated with a 4- to 7-fold higher relative risk of having ≥ 2 cardiometabolic risk factors when comparing obese II+ to normal-weight adults in each sex-by-race group. Within each BMI category, higher WC also was associated with a significantly higher likelihood of elevated cardiometabolic risk. The risk associated with higher waist circumference was not as great in obese II+ men as in the other groups. Once men reach this level of obesity, they likely already have established risk due to their excess total body fat, so waist circumference may not further add to the ability to discriminate risk.

Additionally, the magnitude of the ORs for elevated cardiometabolic risk due to a higher WC varied across races. Normal-weight African Americans had particularly higher ORs for elevated cardiometabolic risk given a higher WC (OR 3.4–3.6), compared to the ORs within the normal-weight white group or the overweight or obese groups (OR 1.1–1.9). Although the ORs indicate differences within each sex, race, and BMI group, the stronger associations between WC and cardiometabolic risk for normal-weight African Americans highlight the need for race-specific WC thresholds.

Based on ROC curve analysis, the optimal WC threshold associated with ≥2 cardiometabolic risk factors varied from 72.1 cm in normal-weight white women to 120.1 cm in obese II+ white men. Adults in lower BMI categories had lower optimal WC thresholds than obese

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Table 4. Sex- and race-specific clinical guidelines for the use of waist circumference within BMI categories to assess health risk based on analyses of the Pennington Center Longitudinal Study*

	Waist circumference threshold within BMI category, cm†			
	normal weight (18.5–24.9 kg/m²)	overweight (25–29.9 kg/m²)	obese I (30–34.9 kg/m²)	obese II+ (≥35 kg/m²)
White women	≥72	≥87	≥97	≥111
African American women	≥76	≥85	≥97	≥110
White men	≥82	≥95	≥107	≥120
African American men	≥78	≥92	≥104	≥119

*Health risk defined as ≥2 cardiometabolic risk factors of the following: blood pressure ≥ 130/85 mm Hg (or reported treated hypertension); glucose ≥ 100 mg/dl (or diagnosed with diabetes); triglycerides ≥ 150 mg/dl; or HDL cholesterol < 40 mg/dl for men or < 50 mg/dl for women.

†Waist circumference threshold indicates increased health risk within each BMI category and sex-by-race group.

adults for discriminating elevated cardiometabolic risk. The range in WC thresholds of 48 cm indicates the need to consider BMI category when using WC thresholds to discriminate cardiometabolic risk. Moreover, WC thresholds varied by approximately 10 cm across sex-by-race groups within each BMI category, indicating the importance of sex- and race-specific thresholds. The sensitivity and specificity between races, within sex group, varied as much as 15.7%, indicating that a large number of individuals would be misclassified if race-specific thresholds were not used.

The sensitivity and specificity of thresholds indicate the accuracy of detecting elevated health risk based on WC. If a threshold is set too high, sensitivity is sacrificed and the number of false negatives increases, meaning a person who is indeed at elevated health risk is likely to be missed. If a threshold is set too low, specificity is sacrificed and the number of false positives increases, meaning a person is likely to be incorrectly classified as having an elevated health risk. In the present analysis, sensitivities ranged from 52.7 to 73.3% and specificities from 57.1 to 73.5%. These are similar to the range in sensitivities of 59.7–71.9% and the range in specificities of 51.7–66.3% for WC thresholds within BMI category, as found in the study of the Third US National Health and Nutrition Examination Survey (NHANES III) [7], indicating a satisfactory ability to classify health risk.

Current recommended WC thresholds used to discriminate elevated cardiometabolic risk are 88 cm for women and 102 cm for men [5]. Compared to these current guidelines, the BMI-specific WC thresholds had higher sensitivities in normal-weight and overweight sex-by-race groups. High sensitivity is a desirable outcome for detecting elevated risk in individuals who may appear healthy by current WC guidelines but in fact are at risk. Specificities were higher for the BMI-specific WC thresholds versus current guidelines, indicating individuals not at cardiometabolic risk were more likely to be correctly classified as such. High specificity for obese groups is also desirable in medical practice, to avoid unnecessary tests for individuals who do not have a high WC considering their BMI category.

The current NIH guidelines are 1–16 cm higher than the present study's optimal WC thresholds for normal-weight and overweight adults. In contrast, the recommendations are 2–23 cm lower than the present study's thresholds for obese adults. Similarly, thresholds developed for obese African American adults were lower than the present study's thresholds [10]. The PCLS thresholds are also consistently lower (ranging from 2 to 8 cm) than BMI-

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specific WC thresholds established for white and black men and women based on the NHANES III [7]. Differences between PCLS and NHANES thresholds tend to be larger between women (average difference of 6 cm) versus those for men (average difference of 3.5 cm).

There are several potential explanations for the discrepancies in WC thresholds. One is a difference in measurement site for WC. A comparison of four commonly used WC measurement sites revealed systematic differences in magnitude [11], and the clinical utility of WC to discriminate cardiometabolic risk may vary by anatomical location [12]. However, when examining differences in measurement sites between the NHANES (iliac crest) and the PCLS (midpoint between iliac crest and lowest rib), the average midpoint WC was only 2 cm less than the average WC at the iliac crest in women, and there was no difference in men [11]. These minor differences indicate that measurement site may only partially explain differences in WC thresholds.

A second potential explanation for differing WC thresholds is that the outcome measure differs: the present study used the presence of ≥2 cardiometabolic risk factors as an indication of elevated health risk, whereas other studies compute WC thresholds based on correspondence to a BMI of 30 kg/m^2 [8] or use another indicator of cardiometabolic risk such as Framingham Risk Scores [7]. Therefore, associations may differ based on the health outcome. A third potential explanation is that the study samples differ: for instance, the NHANES is a representative sample of US residents, whereas the PCLS is a volunteer sample recruited from a city in the southeast of the USA.

A major strength of this study is the sample, which includes white and African American men and women with a range of BMI, WC, and cardiometabolic health risk, and therefore provides sufficient variability to estimate thresholds. The inclusion of African American adults is particularly beneficial, considering a recent review of the literature found that evidence is insufficient to create WC cutoffs for African American populations [13] though one recent study did establish WC thresholds for African American and white men and women [9]. A second strength is the WC measurement site, which is the site currently recommended by the World Health Organization [14] making these thresholds therefore applicable to current clinical practices. However, limitations of the study warrant discussion. The PCLS is not a representative sample of the entire US population, and therefore generalizability of the WC thresholds is limited. These WC thresholds need to be cross-validated in other populations. Differences in social class may influence the observed association between WC and cardiometabolic risk, but information on education or income was not available. Age stratification may be an additional consideration for WC thresholds [1]. However, further analyses that tested a potential age by WC interaction in the logistic regression models reported in table 2 found no indication of a significant interaction. Additionally, this study used cross-sectional data to link WC to health risk, and a longitudinal design would be preferable to identify predictors of future obesity-associated health risks.

In conclusion, differences in optimal WC thresholds across BMI categories and across sex-by-race groups reveal that the currently recommended single WC thresholds may limit the utility of WC at identifying people with elevated health risks. BMI-specific WC thresholds had higher sensitivity in normal-weight and overweight groups and higher specificity in obese I and obese II+ groups compared to current guidelines. To improve the accuracy of discriminating health risk based on anthropometry, WC thresholds that are stratified by BMI, sex, and race should be used in clinical settings. It is recommended that the PCLS WC thresholds be used provisionally in public health research and clinical practice until representative standards of white and African American men and women become available based on data from longitudinal studies.

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Disclosure Statement

The authors declare no conflicts of interest. P.T.K. and A.E.S. had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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