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Developing equations to predict waist circumference measurements based on the National Heart, Lung, and Blood Institute method from the World Health Organization method

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Abstract

Purpose: The purpose of the study was to convert waist circumference (WC) measurements obtained by the World Health Organization (WHO-WC) method to the National Heart, Lung, and Blood Institute (NHLBI-WC) method.

Methods: During 2016, the National Health and Nutrition Examination Survey participants aged 20 years and older had two different WC measurements taken ($n = 2405$). The mean differences in the WC between the NHLBI-WC and WHO-WC measurements were calculated. Multivariable prediction models were developed to predict the NHLBI-WC from the measured WHO-WC. Sensitivity and specificity of the abdominal obesity classification (AOC) were calculated for the measured WHO-WC and the predicted NHLBI-WC. Kappa coefficients were calculated to evaluate the agreements between the AOC derived from the NHLBI-WC and from the WHO-WC and the predicted NHLBI-WC.

Results: The mean differences between the NHLBI-WC and WHO-WC were 0.8 cm for males and 3.2 cm for females ($P \leq .05$). Sensitivity of the AOC for the measured WHO-WC was 93% for males and 87% for females, and the specificity of the AOC was 97% or greater for both genders. Sensitivity and specificity of the AOC for the predicted NHLBI-WC were 95% or greater for both genders. The AOC derived from the predicted NHLBI-WC had higher agreements for both genders.

Conclusions: The prediction equations provided may be used to predict the NHLBI-WC from the WHO-WC for comparability in WC estimates across studies.

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Keywords

Waist circumference; NHANES; Measurement

Introduction

The waist circumference (WC) is a proxy for measuring abdominal obesity, a risk factor associated with increased visceral fat stores, which is associated with an increased risk for type 2 diabetes, high blood pressure, and cardiovascular disease [1–5]. There are a number of different protocols to measure the WC in a clinical or research setting. A widely used measurement is the protocol used by the World Health Organization (WHO) and implemented by several European surveys, the Korean National Health and Nutrition Examination Survey (NHANES), and before 2009 by the Canadian Health Measures Survey [6–10]. The WHO waist circumference (WHO-WC) is measured at the approximate midpoint between the lower margin of the last palpable rib and the top of the iliac crest [6]. Currently, the NHANES measures the WC using a protocol recommended by the National Heart, Lung, and Blood Institute (NHLBI), which measures waist circumference (WC) above the uppermost border of the iliac crest [11]. The NHLBI-WC has been used by the NHANES since the year 1988.

In 2016, during the administration of the 2015–2016 NHANES, participants aged 20 years and greater participated in a methodology study which compared five methods of WC measurements including the WHO and NHLBI protocols. Details of this methodology study have been previously published [12]. The calculated sensitivity and specificity for abdominal obesity measured by the WHO protocol, with the NHLBI-WC as a reference, for males were 94.2% and 96.2%, respectively. However, among females, the mean WHO-WC was lower than that of the NHLBI-WC, which led to low sensitivity (86.85%) and high specificity (99.63%); that is, those who were classified as having abdominal obesity using the NHLBI-WC had a lower chance to be classified as having abdominal obesity using the WHO-WC because the latter was measured 3 cm lower on average [12].

The objective of this study was to construct multivariable regression equations to facilitate comparison in WC measurements between the NHLBI-WC and WHO-WC measurement protocols in the U.S. population using a large representative sample of the U.S. noninstitutionalized population aged 20 years and older.

Methods

Survey description

The NHANES is a cross-sectional national health survey of the civilian noninstitutionalized U.S. population. Descriptions of the NHANES sample design and data collection methods are available on the NHANES website at www.cdc.gov/nhanes. The NHANES mobile examination centers (MECs) travel to 15 locations each year [13], and participants receive a detailed in-person home interview followed by physical assessments at an MEC. All procedures in the NHANES, including the WC measurement study, were approved by the

National Center for Health Statistics (NCHS) Research Ethics Review Board, and written informed consent was obtained from all participants.

Sample

During 2016, 2781 adults aged 20 years and older were eligible for the methodology study, which is described in detail elsewhere [12]. Adults with a missing NHLBI-WC or WHO-WC measurement (n = 351) or who were pregnant (n = 25) were excluded from the current analyses. The final analytic sample consisted of 2405 (86%) participants.

Waist circumference measurements

Both the NHLBI-WC and WHO-WC were measured using a Lufkin metal tape [11,12].

NHLBI-WC measurements were obtained using a standardized protocol used in the NHANES since 1988 (NHANES III). The NHLBI-WC measurement protocol had a health technician (HT) extend the Lufkin measuring tape around the waist at the uppermost border of the iliac crest with the help of a mirror and with assistance from a second person (recorder) to assure that the tape was horizontal to the floor with no gapping or constriction. The HT then read the measurement at the right side to the nearest 0.1 cm at the end of the participant's normal respiratory expiration. This measurement was taken only once [11].

After the WHO protocol, for the WHO-WC measurement, the HT stood at the participant's right side and drew a line at the uppermost lateral border of the right iliac crest and the lower margin of the last palpable rib. Then, the HT used the two lines to obtain the midpoint; the HT extended the Lufkin measuring tape around the waist at the level of the midpoint with the help of a mirror and with assistance from a second person (recorder) to assure that the tape was horizontal to the floor with no gapping or constriction. The HT then read the measurement to the nearest 0.1 cm at the end of the participant's normal respiratory expiration [12]. This measurement was taken only once.

Abdominal obesity

Following the National Heart, Lung, and Blood Institute guidelines for managing overweight and obesity in adults, abdominal obesity is classified as a measured WC > 102 cm for males and >88 cm for females [14].

Demographic covariates

Demographic covariates included the gender, age in years, and race and Hispanic origin. The race and Hispanic origin, based on self-reported information, are publicly released as non-Hispanic white, non-Hispanic black, non-Hispanic Asian, and Hispanic. Participants not fitting the aforementioned self-classification were classified as "other." Data for the "other" group, including persons who reported multiple races, were included in the total sample results but because of small sample sizes are not reported separately in the result tables.

Other covariates

As per the standard NHANES anthropometry measurements, the weight was recorded in kilograms using a digital scale while the participant wore a standardized two-piece

examination outfit. The height in centimeters was obtained using a stadiometer with a fixed vertical backboard and an adjustable headpiece. The body mass index (BMI) was calculated as weight in kilograms over height in meters squared (kg/m^2) and was categorized using criteria established by the National Institutes of Health as underweight (<18.5 kg per m^2), normal (18.5–24.9 kg per m^2), overweight (25.0–29.9 kg per m^2), and obese (≥30 kg per m^2) [14]. Owing to the relatively small number of participants in the underweight category, the underweight category was combined with the normal category after a sensitivity analysis showed no significant difference in the results, whether the underweight category was excluded or included in the normal weight category.

Study design

The order of the two protocols (NHLBI-WC and WHO-WC) was randomized, and the measurements were performed directly on the skin in the standardized MEC environment. The WC component of the NHANES automated information technology system was updated with prompts to ensure that the HT and the recorders were performing the correct protocol with the correct data entry screen in the order the randomization process was assigned [11].

Statistical analyses

All statistical analyses were stratified by gender and performed using survey procedures in SAS, version 9.4, for Windows (SAS Institute, Inc., Cary, NC) and SUDAAN 11.0 software (Research Triangle Institute, Research Triangle Park, NC). The mean WC was derived for each measurement method, overall, and within selected covariates (age group, race/Hispanic origin, obesity category). For this analysis, the age was categorized into the following groups: 20–39, 40–59, and 60 years or more. Using the NHLBI-WC as the reference, the means of the difference between the NHLBI-WC and WHO-WC were calculated. Paired *t*-tests were used to test if the mean difference between two measurements was statistically significantly different from zero. Estimates presented in this paper comparing the NHLBI-WC and the WHO-WC may slightly vary from the main methodology study, which examined 5 different WC measurement methods and therefore had more exclusion of data because of the missingness of any of the 5 WC measurements [12].

The data were collected only for a single year (2016) rather than a typical NHANES two-year data collection period. Therefore, the single year weights, available through the NCHS Research Data Center, were used for all statistical analyses. The Jackknife method (i.e., deletes one primary sampling unit at a time) rather than Taylor Series Linearization was used for variance estimation [15]. The WC measurement study data set is also available through the Research Data Center (website).

To construct and validate the prediction models separately, the analytic sample was randomly split into two subsets with about 50% observations in each subset. One subset was used as the training group (i.e., data from this group were used to construct prediction models). The other subset was used as the test group (i.e., the prediction models derived from the training group were applied to the test group to test the validity of the models). Outliers (differences between the NHLBI-WC and WHO-WC beyond three times the SD)

were removed from the training group data (n = 6 (or 1.0%) for males, n = 8 (or 1.3%) for females). No outliers were removed from the test group data.

Multivariable linear regression models were fit to the training data, with the NHLBI-WC as the response variable and the WHO-WC and selected covariates (age in years as a continuous covariate, race and Hispanic origin, obesity category) as predictors (SAS, SURVEYREG procedure). Quadratic and cubic terms of the WHO-WC and the interactions of the predictors were tested, and the best prediction models were selected based on R-squared values. Prediction models contain only statistically significant predictors of the NHLBI-WC.

Sensitivity and specificity of abdominal obesity classification based on the different WC measurements (WHO-WC measurements and the predicted NHLBI-WC measurements derived from the prediction models) were calculated (SAS, SURVEYFREQ procedure), where abdominal obesity classification based on the measured NHLBI-WC was used as the reference (>102 cm for males; >88 cm for females). Sensitivity refers to the true positives, that is, the percentage of participants classified as having abdominal obesity using the NHLBI-WC who were also classified as having abdominal obesity using the WHO-WC or the predicted NHLBI-WC. Specificity refers to the true negatives, that is, the percentage of participants classified as not having abdominal obesity using the NHLBI-WC who were also classified as not having abdominal obesity using the WHO-WC or the predicted NHLBI-WC.

The agreements between the abdominal obesity classification derived from the NHLBI-WC and those derived from the WHO-WC and the predicted NHLBI-WC were evaluated using Kappa coefficients, where a Kappa coefficient close to 1 corresponds to a higher agreement [16].

Kernel density distributions of both predicted and measured WC by gender were graphically displayed using Proc SGPLOT procedure (SAS, 9.4).

Results

The unweighted sample sizes for males and females by age group, race, Hispanic origin, and weight status are described in Table 1. Tables e-1a and e-1b compare the means and differences between the NHLBI-WC and WHO-WC by covariates. The NHLBI-WC measured significantly higher (P < .05) than the WHO-WC (0.8 cm for males and 3.2 cm for females).

Tables 2 shows the parameter estimates and the associated standard errors for the constructed prediction models, stratified by gender. Linear, quadratic, and cubic terms of the WHO-WC and age were included in the prediction models for both males and females. Age was used as a continuous variable. Race and Hispanic origin and BMI categories were excluded from the prediction models because they did not lead to a difference in the models for both males and females and because the BMI is highly correlated with the WC. The R^2 values were .99 for males and for .98 females. Below are the regression equations predicting NHLBI-WC measurements from WHO-WC measurements.

Based on the test data, among males, percentages of abdominal obesity defined by the NHLBI-WC, WHO-WC, and the predicted NHLBI-WC were 44.7%, 43.3%, and 44.9%, respectively; among females, the corresponding percentages of abdominal obesity were 70.9%, 61.7%, and 68.4%, respectively. Table 3 shows sensitivity and specificity of abdominal obesity by gender, where abdominal obesity defined by the NHLBI-WC was the reference. Both sensitivity and specificity were greater than 0.85 for abdominal obesity defined from the WHO-WC (sensitivity = 0.93 and 0.87 for males and females, respectively; specificity = 0.97 and 0.997 for males and females, respectively). For abdominal obesity derived from the predicted NHLBI-WC, sensitivity and specificity were like those for males using the WHO-WC (sensitivity = 0.96 and specificity = 0.97). While for females, the abdominal obesity based on the predicted NHLBI-WC had a relatively higher sensitivity and a slightly lower specificity (sensitivity = 0.95 and specificity = 0.97) than those derived from the WHO-WC. The changes in sensitivity and specificity for females were due to the greater difference between the WHO-WC and NHLBI-WC among females.

Males	$NHLBI\_WC\_predicted = -0.554 + 1.128*(WHO\ WC) - 0.002*(WHO\ WC)^2 + 0.0000053*(WHO\ WC)^3 - 0.020*(age)$
Females	$NHLBI\_WC\_predicted = -8.61 + 1.452*(WHO\ WC) - 0.005*(WHO\ WC)^2 + 0.000018*(WHO\ WC)^3 - 0.017*(age)$

The agreements of the abdominal obesity classification were higher for the predicted NHLBI-WC than the measured WHO-WC, especially among females (for males), Kappa coefficients were 0.90 (95% CI = 0.85, 0.95) for the WHO-WC and 0.93 (95% CI = 0.89, 0.97) for the predicted NHLBI-WC; for females, Kappa coefficients were 0.79 (95% CI = 0.68, 0.91) for the WHO-WC and 0.90 (95% CI = 0.85, 0.96) for the predicted NHLBI-WC.

Figures 1 and 2 present the kernel density function graphs of the measured and the predicted WC by gender. Among males, the predicted NHLBI-WC using the NHANES regression model closely approximated the measured NHLBI-WC values. Among females, the larger differences between the measured WHO-WC and measured NHLBI-WC values are evident by the nonoverlapping distributions. The predicted NHLBI-WC values using the NHANES regression model closely approximates the measured NHLBI-WC values with nearly overlapping distributions.

Discussion

This analysis provides crossover regression equations by gender among the U.S. population that may be used to convert WHO-WC measurements to NHLBI-WC measurements. Sensitivity and specificity of abdominal obesity based on predicted NHLBI-WC values were greater than 0.95. Among females, sensitivity of abdominal obesity classification increased 8% (from 87% for the WHO-WC to 95% for the predicted NHLBI-WC), whereas for males, there was less difference between the WHO-WC and the predicted NHLBI-WC. This is because the differences between the WHO-WC and NHLBI-WC measurements were greater in females than in males (mean differences were 3.2 cm in females vs. 0.8 cm in males).

To the best of our knowledge, the only other epidemiologic study which generated regression equations from the WHO to the NHLBI was the Canadian study whose objectives were to compare historical WHO-WC data with the NHLBI-WC as to preserve the legacy WHO-WC data [10]. However, their study lacked representation of a racially/ethnically diverse population and was generalized to the noninstitutionalized Canadian population. Both equations included age as a predictor. In addition to the linear term, NHANES equations included a quadratic and a cubic term of the measured WHO-WC to capture the curvilinear relationship between the measured WHO-WC and NHLBI-WC.

The findings in this study are subject to limitations. Although the WC measurements were taken at the MEC in a standardized environment by trained HTs who were evaluated by an interevaluator quarterly, it is still possible that some of the WC measurements taken by the HTs were measured with errors. In addition, only one WC measurement was obtained for each WC protocol, and no intratechnician calibration was performed.

The strength of this analysis is the use of NHANES' one-year nationally representative sample of participants aged 20 years and older, with information on the race and Hispanic origin. It also allowed a large sample to develop a training and testing data set for the prediction equations. Power for testing the differences between the two measurements was high (power >0.99 for both males and females) based on the power analysis using variance estimates from the present WC study, assuming a mean difference of 1.5 cm between the two measurements (NHLBI vs. WHO-WC). In addition, the reliability of these WC measurements was evaluated by "a trainer" interevaluator [11]. Finally, after extensively reviewing WC measurement protocols, Ross et al. recommended that WHO-WC and NHLBI-WC protocols should be used to measure the WC by health-care providers and the general public. The reason behind the recommendations was the fact that both protocols use palpable bony landmarks to identify and facilitate the proper WC measurements [17].

Conclusion

To our knowledge, this is the first study predicting the NHLBI-WC from the WHO-WC using a large representative sample of the U.S. noninstitutionalized population aged 20 years and older. Although the published methods for WC measurements can vary, this study showed that using predicted equations from the measured WHO-WC can lead to equally valid classification of abdominal obesity among males and females. Finally, the NHANES calibration equations may be used to evaluate trends in older NHANES data.

Acknowledgments

Authors' contributions: Y.O., the lead author, contributed to concept development, data analysis, draft manuscript, and revise manuscript; G.Z. contributed to concept development, data analysis, and critical review; and Q.G., S.I., J.P.H., and J.S. contributed to concept development and critical review.

Appendix

Table e-1a

Weighted mean and standard error of waist circumference measurements among males by the NHLBI and WHO methods, the NHANES 2016

	n	NHLBI		WHO		Difference (NHLBI-WHO)	
		Mean	SE	Mean	SE	Mean	SE
Variable							
All	1185	100.9	0.9	100.1	0.9	0.8 *	0.1
Age group							
20–39	413	96.5	1.5	95.2	1.6	1.3 *	0.1
40–59	397	102.2	0.7	101.6	0.7	0.7 *	0.2
60+	375	106.1	0.8	105.8	0.8	0.2	0.2
Race and Hispanic origin							
Hispanic	202	100.7	1.8	100.1	1.9	0.6 *	0.2
Non-Hispanic white	426	101.9	1.2	101.0	1.3	0.8 *	0.1
Non-Hispanic black	304	99.4	1.3	98.7	1.1	0.7 *	0.2
Non-Hispanic Asian	202	90.8	0.9	89.9	1.0	1.0 *	0.1
Weight status							
Underweight/normal	354	84.4	0.7	83.0	0.7	1.5 *	0.1
Overweight	452	98.4	0.5	97.7	0.6	0.7 *	0.2
Obesity	377	116.0	0.9	115.5	0.9	0.4	0.2

SE = standard error.

The sum of the difference and the WHO mean may not equal to the NHLBI mean because of rounding.

* Significantly different from the NHLBI value ($P \leq .05$).

Source: The NCHS, NHANES 2016.

Table e-1b

Weighted mean and standard error of waist circumference measurements among females by the NHLBI and WHO methods, the NHANES 2016

	n	NHLBI		WHO		Difference (NHLBI-WHO)	
		Mean	SE	Mean	SE	Mean	SE
Variable							
All	1220	97.6	1.0	94.4	1.0	3.2 *	0.1
Age group							
20–39	415	92.3	1.1	88.8	1.1	3.5 *	0.1
40–59	432	100.0	1.5	96.9	1.6	3.1 *	0.3
60+	373	101.5	1.8	98.7	1.7	2.8 *	0.2
Race and Hispanic origin							
Hispanic	262	97.8	1.4	95.0	1.3	2.8 *	0.2
Non-Hispanic white	411	97.7	1.3	94.3	1.3	3.4 *	0.2
Non-Hispanic black	311	101.7	1.3	99.2	1.2	2.5 *	0.2
Non-Hispanic Asian	192	85.9	0.8	83.0	1.0	2.9 *	0.2

	n	NHLBI		WHO		Difference (NHLBI-WHO)	
		Mean	SE	Mean	SE	Mean	SE
Weight status							
Underweight/normal	411	81.5	0.6	78.0	0.6	3.5 *	0.1
Overweight	317	94.7	0.6	91.6	0.5	3.1 *	0.1
Obesity	491	113.2	1.1	110.3	1.0	2.9 *	0.3

SE = is standard error.

The sum of the difference and the WHO mean may not equal to the NHLBI mean because of rounding.

* Significantly different from the NHLBI value ($P \leq .05$).

Source: The NCHS, NHANES 2016.

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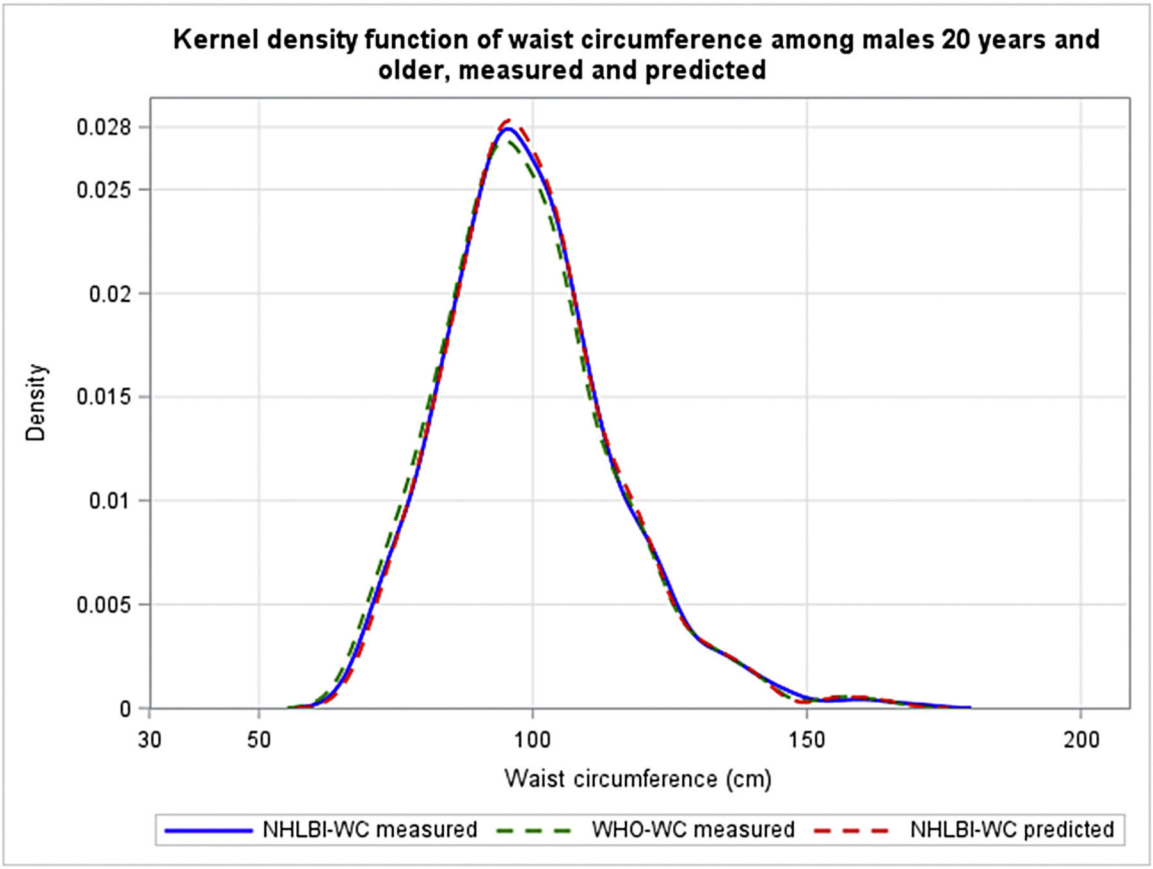

Fig. 1.

Kernel density function of the waist circumference among males 20 years and older, measured and predicted.

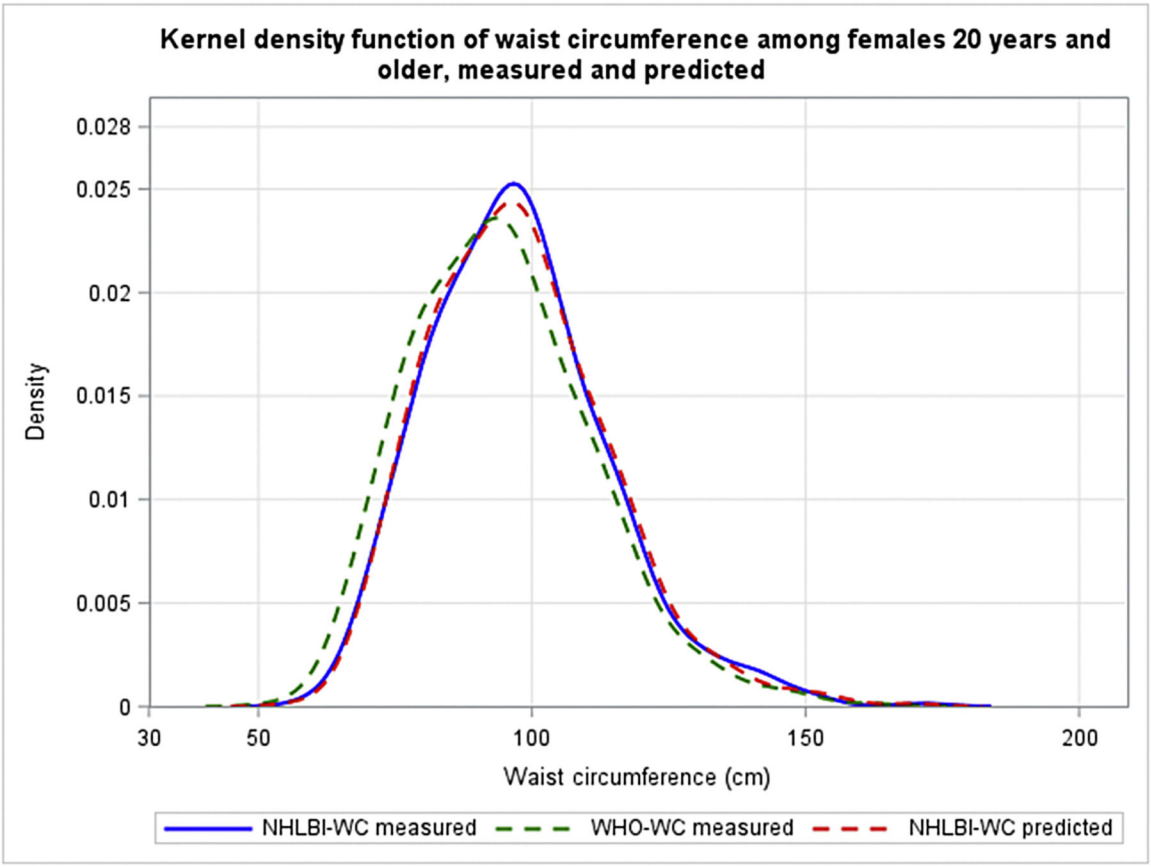

Fig. 2.

Kernel density function of the waist circumference among females 20 years and older, measured and predicted.

Table 1

Unweighted sample sizes for U.S. adults aged 20 years or older with the NHLBI and WHO waist circumference measurements by sex, age group, race and Hispanic origin, and weight categories

Characteristics	No. of participants	
	Males	Females*
All	1185	1220
Age group		
20–39	413	415
40–59	397	432
60+	375	373
Race and Hispanic origin		
Hispanic	202	262
Non-Hispanic white	426	411
Non-Hispanic black	304	311
Non-Hispanic Asian	202	192
Weight status		
Underweight/normal	354	411
Overweight	452	317
Obesity	377	491

From: The National Health and Nutrition Examination Survey, 2016.

*Pregnant women were excluded.

Source: The NCHS, NHANES 2016.

Table 2

Parameter estimates and standard errors of the models for predicting the NHLBI-WC based on the waist circumference measured using the WHO method, by gender, the NHANES 2016

Variable	Males				Females			
	Estimate	SE	*P*-value	R^2	Estimate	SE	*P*-value	R^2
Intercept	−0.554	11.16	.96	0.99	−8.61	7.64	.27	0.98
WHO-WC	1.128	0.34	.004		1.452	0.23	<.0001	
WHO-WC^2	−0.002	0.003	.64		−0.005	0.002	.04	
WHO-WC^3	0.0000053	0.00	<.0001		0.000018	0.00	<.0001	
Age	−0.020	0.01	.01		−0.017	0.008	.04	

SE = standard error.

Source: The NCHS, NHANES 2016.

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Table 3

Sensitivity and specificity of the WHO and the NHLBI predicted values in defining abdominal obesity with the NHLBI-WC values defining the gold standard, the NHANES 2016

	WHO-WC		NHLBI predicted	
	Sensitivity	**Specificity**	**Sensitivity**	**Specificity**
Males *	0.93	0.97	0.96	0.97
Females †	0.87	0.997	0.95	0.97

Results were based on test data. Abdominal obesity is defined as a WC of >102 cm for males and >88 cm for females.

* Kappa coefficients were 0.90 (95% CI = 0.85, 0.95) for the measured WHO-WC and 0.93 (95% CI = 0.89, 0.97) for the predicted NHLBI-WC.

† Kappa coefficients were 0.79 (95% CI = 0.68, 0.91) for the measured WHO-WC and 0.90 (95% CI = 0.85, 0.96) for the predicted NHLBI-WC.

Source: The NCHS, NHANES 2016.