$$\sqrt{\frac{p(1-p)}{n}} \leq 0.075$$

$$\hat{\theta} = \frac{\sum_{h=1}^{L} \hat{Y}_h}{\sum_{h=1}^{L} \hat{T}_h}$$

$$z_{hij} = \frac{w_{hij}\delta_{hij}(Y_{hij} - \hat{\theta})}{\sum_{h=1}^{L} \hat{T}_h}$$

$$n' = \delta_{APD}\gamma_{CLD}\delta_{INT}\delta_{ELG}\delta_{SCR}\delta_{WRN}\delta_{RES} \, nD$$

$$v(\hat{\theta}) = \sum_{h=1}^{L} \frac{n_h}{n_h - 1} \sum_{i=1}^{n_h} (z_{hi} - \bar{z}_h)^2$$

$$\hat{Y}_h = \sum_{i=1}^{n_h} \sum_{j=1}^{m_{hi}} w_{hij}\delta_{hij}Y_{hij}$$

$$\hat{Y}_{Da} = \lambda_a \hat{Y}_{L(D)a} + (1 - \lambda_a)\hat{Y}_{C(D)a}$$

$$Bias\{\hat{Y}_{L(Proxy\,CPO)a}\} = E\{\hat{Y}_{L(Proxy\,CPO)a} - \hat{Y}_{C(CPO)a}\}$$

Waist Circumference Measurement Methodology Study: National Health and Nutrition Examination Survey, 2016

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Waist Circumference Measurement Methodology Study: National Health and Nutrition Examination Survey, 2016

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Abstract

Objective

This report compares five methods of waist circumference (WC) measurements: 1) the National Heart, Lung, and Blood Institute (NHLBI-WC); 2) the World Health Organization (WHO-WC); 3) the Multi-Ethnic Study of Atherosclerosis (MESA-WC) using Gulick II Plus tape; 4) the Multi-Ethnic Study of Atherosclerosis (MESA-WC) using Lufkin tape; and 5) assisted self-measurement over clothes (MESA-assisted).

Method

During 2016, measurements were obtained from 2,297 participants aged 20 and over, who participated in the National Health and Nutrition Examination Survey (NHANES). The mean differences and sensitivity and specificity for abdominal obesity (AO) were calculated between the NHLBI-WC (reference) and the other four WC measurements.

Results

The mean difference between NHLBI-WC and WHO-WC was 0.81 cm for men and 3.21 cm for women ($p \leq 0.0125$ for both); between NHLBI-WC and MESA-WC (Gulick) was −0.68 cm for men ($p \leq 0.0125$) and −0.89 cm for women; between NHLBI-WC and MESA-WC (Lufkin) was 0.02 cm for men and 0.08 cm for women; and between NHLBI-WC and MESA-assisted was −0.71 cm for men and 1.34 cm for women ($p \leq 0.0125$ for both). Sensitivity and specificity for AO, with NHLBI-WC as a reference, for men were greater than 90% for all methods; for women, sensitivity and specificity for AO for MESA-WC (Lufkin) were greater than 90%; for women, WHO-WC, MESA-WC (Gulick), and MESA-assisted methods were greater than 85%.

Conclusion

Aside from the differences between NHLBI-WC and WHO-WC measurements among women, other differences between NHLBI and other protocols were less than or equal to 1.5 cm.

Keywords: abdominal obesity • NHANES

Introduction

Waist circumference (WC) is a measurement used to estimate abdominal subcutaneous and visceral fat stores. Higher values of WC (WC greater than 102 cm for men and greater than 88 cm for women) are associated with an increased risk for type 2 diabetes, high blood cholesterol, high blood pressure, and heart disease (1). The underlying metabolic process for this risk factor is insulin resistance syndrome associated with increased visceral fat stores (1). Increased WC is also one of the diagnostic criteria for metabolic syndrome, which is highly correlated with cardiovascular diseases (1–4). A number of factors are associated with the variation in visceral adipose tissue distribution, including body mass index (BMI), age, sex, and race and ethnicity (1).

The National Health and Nutrition Examination Survey (NHANES) collects data on selected chronic diseases, such as cardiovascular disease and diabetes. Since 1988 to the present, NHANES measures WC in the mobile examination center (MEC) using a protocol recommended by the National Heart, Lung, and Blood Institute, referred to as NHLBI-WC (5–7). However, there are a number of different protocols to measure WC in clinical or research settings. Among them are the World Health Organization (WHO) protocol, referred to as WHO-WC and the Multi-Ethnic Study of Atherosclerosis (MESA) protocol, referred to as MESA-WC (8,9).

Since its inception in 1956, NHANES has provided a platform to test and explore methodologies (9). Given that there are several protocols being used by other studies and organizations to measure WC, the National Center for Health Statistics (NCHS) undertook a methodology study

embedded in the usual NHANES survey operations protocol to test and compare different methods of WC measurement.

Each protocol measures WC at a different anatomical landmark. NHLBI-WC measures WC at the level of the iliac crest. WHO-WC measures WC at the midpoint between the highest point of the iliac crest and the lowest rib. MESA-WC measures WC at the level of the umbilicus. Out of the three WC measurements, MESA is the least intrusive, requiring minimal skin exposure, whereas the other two involve more skin exposure to obtain measurements. Also, a number of studies have shown that MESA-WC and variations of MESA-WC (e.g., measurement 1 inch above the umbilicus) could be self-measured over clothing, and the measurement obtained was an independent and significant indicator for obesity-related health risks (10–12). However, the validity of self-measuring MESA-WC has been questioned, by recent studies (13,14). Given the potential for this type of approach to be used in studies where less skin contact and exposure may be desirable or necessary, a fourth protocol, the MESA-assisted, was tested, which consisted of measurements taken by a participant over clothing with assistance from a trained health technician if necessary. The aim of this methodology study was to compare WC measurement values obtained by NHLBI-WC, the reference, to WHO-WC, MESA-WC using Gulick II Plus tape, MESA-WC using Lufkin, and MESA-assisted.

Methods

Survey Description

NHANES is conducted by NCHS to assess the health and nutritional status of a representative sample of the noninstitutionalized civilian U.S. population. Descriptions of the NHANES sample design and data collection methods are available on the NHANES website from: https://www.cdc.gov/nhanes. Participants in NHANES receive a detailed in-person home interview followed by physical assessments at a MEC. All procedures in NHANES, including the WC measurement study, were approved by the NCHS Research Ethics Review Board, and written informed consent was obtained from all participants.

Waist Circumference Methodology Study Design

The purpose of the study was to compare four protocols to obtain WC measurements: 1) WHO-WC, 2) MESA-WC using Gulick II Plus tape, 3) MESA-WC using Lufkin, and 4) MESA-assisted with NHLBI-WC, which is the standard reference protocol. The main intent was to assess similarities and differences among these protocols. However, it should be emphasized that there is no plan to change how WC is collected in NHANES, namely using the NHLBI protocol. The data collected from the WC measurement study are available to researchers via a restricted-use data file, which can be accessed through the NCHS Research Data Centers (RDC) from: https://www.cdc.gov/rdc/.

During NHANES 2016, 2,781 adults aged 20 and over were eligible for the methodology study. Among these adults, 309 never received NHLBI measurements, 25 were pregnant women and therefore excluded, and an additional 150 NHANES participants missed one or more of the other WC measurements. There was a final analytic sample of 2,297 (83%) participants: 1,143 were men and 1,154 were women. The overall response rate for survey years 2015–2016 for adults aged 20 and over was 54.8%.

Five WC measurements were performed during the MEC visit with each eligible NHANES participant. Table A describes the five measurements, which are further described under "outcome variables." MESA-assisted was performed, with coaching from the health technician (HT). The HT alone performed the other four WC measurements over the skin and at the level of the specific anatomical landmarks. The order of four of the protocols (NHLBI-WC, WHO-WC, MESA-WC using Lufkin tape, and MESA-WC using the Gulick II Plus tape) were randomized; see Table B for the randomizing schema for the four HT-obtained WC measurements. 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 assigns. The MESA-assisted part of the study was not randomized as the randomization was only for the measurements obtained directly over anatomical

Table A. Waist circumference measurement protocols for survey participants aged 20 and over for 2016

Protocol	Measurement	Anatomical landmark	Condition	Tape used
MESA-assisted[1]	Coached, self-measure	At the level of the umbilicus	Over street clothing	Gulick
MESA-WC	Health technician	At the level of the umbilicus	On skin	Gulick
MESA-WC	Health technician	At the level of the umbilicus	On skin	Lufkin
WHO-WC	Health technician	At the midpoint between the highest point of the iliac crest and the lowest rib	On skin	Lufkin
NHLBI-WC	Health technician	At the level of the iliac crest	On skin	Lufkin

[1]The MESA-assisted WC measurement was carried out before changing into the MEC examination gown or before leaving the MEC after changing back into street clothes.

NOTES: MESA is Multi-Ethnic Study of Atherosclerosis. WC is waist circumference. WHO is the World Health Organization. NHLBI is National Heart, Lung, and Blood Institute. MEC is mobile examination center.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table B. Randomization order for waist circumference measurement done on skin by health technician

Order	Randomization
1	ABCgl
2	ABClg
3	ACglB
4	AClgB
5	BAClg
6	BACgl
7	BClgA
8	BCglA
9	ClgAB
10	CglAB
11	ClgBA
12	CglBA

NOTES: A is the National Heart, Lung, and Blood Institute. B is the World Health Organization (WHO-WC). Clg is the Multi-Ethnic Study of Atherosclerosis (MESA-WC) Lufkin then Gulick. Cgl is MESA-WC Gulick then Lufkin. WC is waist circumference.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

landmarks while the MESA-assisted component was time independent of the other WC measurements obtained by the HT.

Since NHANES 1999, an outside consultant expert in anthropometric measurement has been observing quarterly the HT doing the measurements. The expert established internal tolerance limits for inter-observer differences for each anthropometric measurement. For the NHLBI-WC, the tolerance limit is ±1.0 cm for a waist circumference measuring less than 100 cm and ±1.5 cm for those measuring greater than or equal to 100 cm. The same tolerance limits were used to assess HT performances obtaining WHO-WC and MESA-WC measurements in the methodology study. Of note, because MESA-assisted was done by the examinee, these criteria were not applied, instead the HT was observed quarterly doing the procedure by the reference evaluator guided by the protocol, and the HT was corrected if they were assisting incorrectly. Moreover, the observed HT was retrained by the reference evaluator if necessary and

observed again to ensure that they were correctly assisting the examinee doing the measurement.

Table C shows the results of the inter-evaluator reliability measurements. For a sample of 60 adults, the mean differences between the reference evaluator and HTs for all protocols was not statistically significant, and all the correlations were at or greater than 0.99. The lowest technical error of measurement was associated with MESA-Lufkin and the highest was associated with NHLBI-WC (6). This evaluation was done during survey year 2016, quarterly.

Equipment

Both the NHLBI-WC and WHO-WC were measured using a Lufkin tape and the MESA-WC was measured using a Gulick tape, the MESA protocol prescribed tape, and a Lufkin tape (Figures 1 and 2). Because of the relatively unintrusive and simple nature of the MESA-WC protocol, there is the possibility of using this method in a less standardized environment, so using two kinds of tapes may give the researchers a better

Figure 1. Lufkin tape

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table C. Reliabilities for waist circumference measurement for 2016

Anthropometric measurement in centimeter (cm)	N	Mean		Mean difference (examiner minus reference)	P value[1]	Technical error of measurement	r value	Outside of tolerance limits for measurement	
		Examiner	Reference					Number[2]	Percent
NHLBI-WC	60	94.5	94.6	−0.06	NS	0.85	0.99	6	10.0
WHO-WC	60	92.4	92.4	−0.05	NS	0.59	0.99	7	11.7
MESA-Lufkin WC	60	94.6	94.7	−0.10	NS	0.38	0.99	3	5.0
MESA-Gulick WC	60	95.3	95.3	0.02	NS	0.55	0.99	6	10.0

[1]Difference is significant by paired *t* test (indicates bias).
[2]Tolerance limit is ±1.0 cm for waist circumference less than 100 cm and ±1.5 cm for those greater than or equal to 100 cm.

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. WC is waist circumference. WHO is the World Health Organization. MESA is Multi-Ethnic Study of Atherosclerosis. NS is not significant. TEM is technical error of measurement (TEM = $\sqrt{(\sum D^2/2N)}$, where D is the difference between measures and N is the number of subjects measured. The *r* values are determined by Pearson correlation coefficients. MESA-assisted was not assessed using these criteria.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Figure 2. Gulick II Plus tape

Figure 3. National Heart, Lung, and Blood Institute waist circumference measurement at the iliac crest

understanding of how they compare with NHLBI-WC. Lastly, because MESA-assisted is a modification of MESA-WC, the protocol used the Gulick II Plus tape (9). This resulted in the only change between the original MESA-WC protocol, and MESA-assisted was the individual doing the measurement.

The Lufkin tape measure is a retractable stainless steel tape measure that is 200 cm (78.7 inch) long and 0.6 cm wide. The Gulick II Plus tape measure is a 1.6 cm wide, 305 cm (120 inch) long, no-stretch, polyester reinforced, retractable tape with both centimeter and inch gradations. The most important part of the Gulick II Plus tape measure is its tensioning device, which provides a known amount of tension while measuring and adds precision to the measurement. Each individual tensioning device is calibrated to indicate precisely a 4-ounce tension.

Outcome Variables

Waist Circumference Measurements

NHLBI-WC, the reference measurement, was obtained following a standardized protocol used in NHANES since 1988 (5). The NHANES HT asked the participant to stand upright with body weight evenly distributed on both feet. The HT, standing at the participant's right side, palpated the hip area to locate the right iliac crest of the pelvis. Then with a cosmetic pencil, the HT drew a horizontal line just above the uppermost lateral border of the right ilium, and crossed this mark at the mid-axillary line. The Lufkin tape measure was extended around the waist at the level of the iliac crest with the help of a mirror and a second person (recorder) to ensure that the tape was horizontal to the floor with no gaps or constrictions. The HT read the measurement to the nearest 0.1 cm at the end of the participant's normal expiration (Figure 3). Only one measurement was taken.
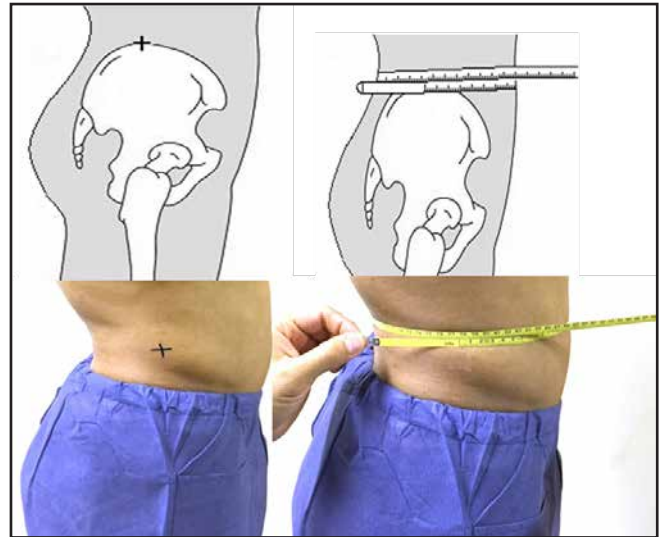
MESA-assisted WC measurements were obtained over street clothes (typically a lightweight shirt) to stimulate the potential of this WC measurement to be used in a home examination, after arriving at the MEC and changing into the examination gown, or before leaving the MEC after changing back into street clothes. These measurements were done in front of a portable standing mirror. The HT instructed participants to point to their umbilicus, gave the participant the Gulick II Plus tape, and asked him/her to pull the tape by grasping the metal tension bar and extending it around the waist at the level of the umbilicus until the ends of the tape met around the waist. The HT verbally assisted the participant by asking him/her to verify the horizontal position of the tape by checking the placement in the mirror. The participants used the mirror as a guide to make sure that the tape level was as straight as possible. If necessary, the HT instructed the participant in which direction to make adjustments. For example, if the tape was lower on the right side of the waist, then the HT told the participant to check the left side and slightly pull up the tape. Once the desired measurement position was obtained, the HT pulled on the tape-tensioning device and recorded the results of the tape measurement to the nearest 0.1 cm. Only one measurement was performed (Figures 4–6).

MESA-WC measurements were obtained twice in a randomized order, once using the Lufkin tape measure (MESA-Lufkin) and once using the Gulick II Plus tape measure (MESA-Gulick) following a standardized protocol. The HT located the participant's umbilicus and, if necessary, lowered the waistband of the pants and underclothing to expose it. The HT moved to the participant's right side and extended the tape measure (Lufkin or Gulick II Plus) around the waist, positioning the tape in a horizontal plane at the level of the umbilicus parallel to the floor. When needed, the HT used the wall mirror to ensure the horizontal alignment of the tape

Figure 4. Belly button location

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Figure 5. Wrapping the Gulick II Plus tape

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Figure 6. Gulick tape–zero line measurement by observer
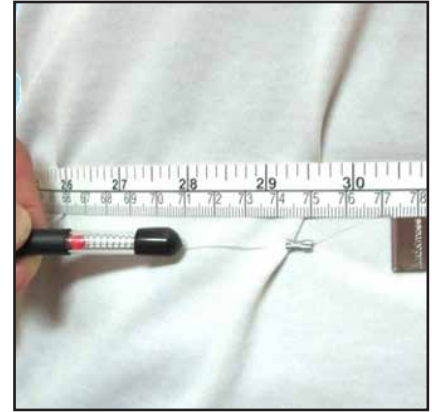
SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

(Figures 7,8). The HT read the measurement to the nearest 0.1 cm at the end of the participant's normal expiration.

WHO-WC measurements were obtained using their standard WHO protocol (8). The HT stood at the participant's right side and drew a line at the uppermost lateral border of the right ilium and the lower margin of the last palpable rib. Then, the HT used the two lines to obtain the midpoint, using a white plastic ruler, and indicated this measurement site using a (+) sign. The WC was measured at the level of the (+) sign using the Lufkin tape measure. The measurement was taken only once (Figure 9). The HT read the measurement to the nearest 0.1 cm at the end of the participant's normal expiration.

Covariates

Demographic Covariates

In addition to sex, results were analyzed by age and race and ethnicity. Age was categorized into the following groups: 20–39, 40–59, and 60 and over. Race and ethnicity, based on self-reported information, was classified as non-Hispanic white, non-Hispanic black, non-Hispanic Asian, and Hispanic. Participants not fitting the above 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 size, the information was not reported separately in the data tables.

Figure 7. Multi-Ethnic Study of Atherosclerosis waist circumference measurement using Lufkin tape

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Figure 8. Multi-Ethnic Study of Atherosclerosis waist circumference measurement using Gulick II Plus tape
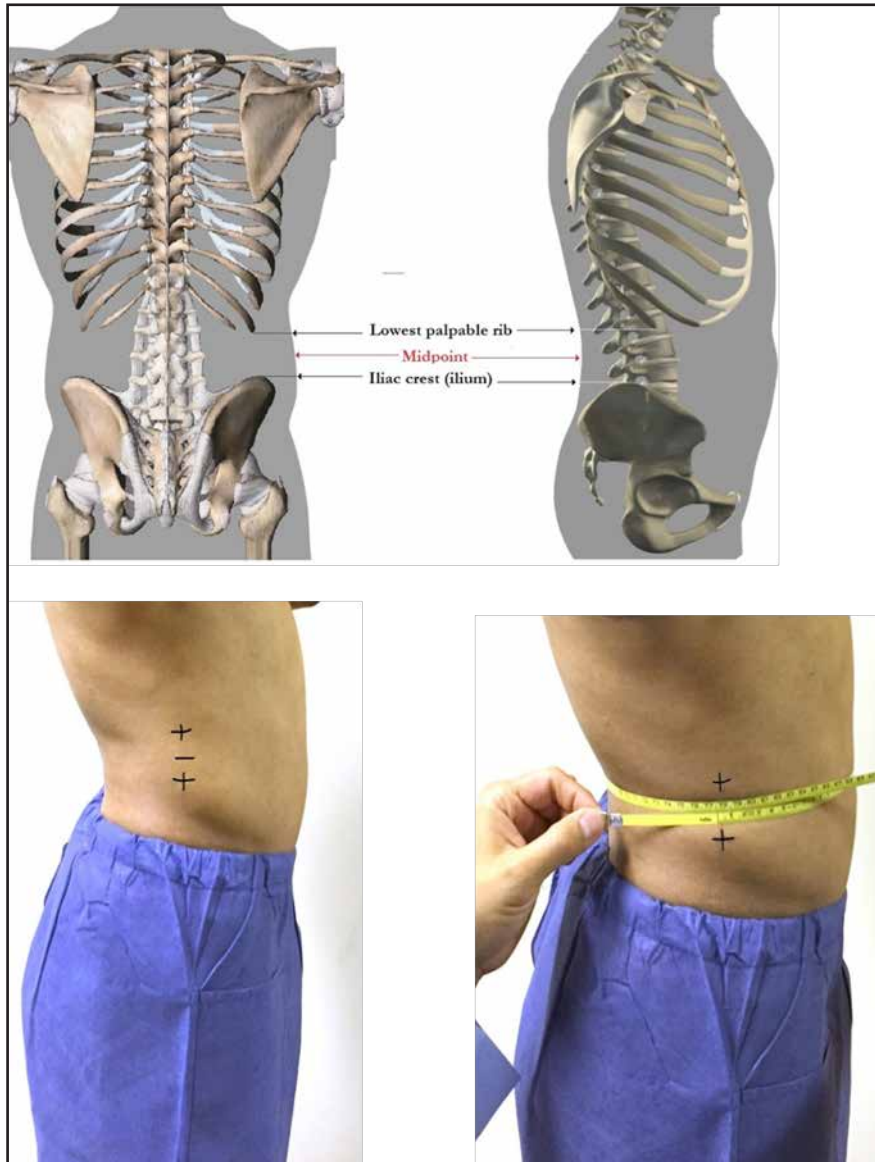

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Figure 9. World Health Organization waist circumference measurement

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Body Mass Index

As per the standard NHANES anthropometry measurements, weights were obtained in kilograms using a digital scale while wearing a standardized two-piece examination outfit. Height in cm was obtained using a stadiometer with a fixed vertical backboard and an adjustable headpiece (6). BMI was calculated as weight in kilograms divided by height in meters squared (kg/m²), and was categorized using criteria established by the National Institutes of Health as underweight (less than 18.5 kg/m²), normal (18.5–24.9 kg/m²), overweight (25.0–29.9 kg/m²), and obese (greater than or equal to 30 kg/m²) (15). Due 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 underweight was excluded or included in the normal weight category.

Statistical Analyses

Mean WC was derived for each measurement method, overall and within selected covariates (age group, race and ethnicity, obesity category). Using the NHLBI-WC as the reference, mean of the difference between NHLBI-WC and four methods (WHO-WC, MESA-WC Gulick, MESA-WC Lufkin, MESA-assisted) was calculated for each. All statistical analyses were stratified by sex and performed using survey procedures in SAS 9.4 for Windows (SAS Institute, Inc., Cary, NC) and SUDAAN 11.0 software (Research Triangle Institute, Research Triangle Park, NC).

The WC study was conducted only during a single year (2016) rather than a typical NHANES 2-year data collection period. Therefore, the single-year weight (WTNA) was used for all statistical analyses. The delete-1-Jackknife method was used for variance estimation (16).

A paired t test was used to test if the mean differences between two measurements were statistically significantly different from zero. Because there were four comparisons (each method compared with NHLBI), Bonferroni correction of 0.05/4 = 0.0125 as the cutoff value of statistical significance was used.

For the purpose of assessing agreement of abdominal obesity classification, where abdominal obesity was classified as a measured WC is greater than 102 cm for men and greater than 88 cm for women, sensitivity and specificity of abdominal obesity defined by different WCs were derived (17). NHLBI-WC-determined abdominal obesity was defined as the reference. All sensitivity and specificity data calculations were based on weighted data.

Sensitivity refers to the true positives (i.e., the percentage of participants classified as having abdominal obesity using NHLBI-WC who were also classified as obese using other WC protocols). Specificity refers to the true negatives (i.e., the percentage of participants classified as not having abdominal obesity using NHLBI-WC who were also classified as not having abdominal obesity using other WC protocols).

Finally, post-hoc power analysis was conducted by sex, using variance estimates from the data of the current WC methodology study described in this paper, to test the null hypothesis that the mean difference between the two

measurements (NHLBI compared with another protocol) was equal to zero.

Results

Tables D and E compare the means of and differences between NHLBI-WC and WHO-WC. Overall, the mean difference between WHO-WC and NHLBI-WC was 0.81 cm for men and 3.21 cm for women, with NHLBI-WC values being, on average, significantly ($p \leq 0.0125$) larger than those of WHO-WC, when stratified by age, race and Hispanic ethnicity, and obesity categories. The differences among men aged 60 and over and with obesity were not statistically significant. For men, the mean differences ranged from 0.20 cm (aged 60 and over) to 1.45 cm (normal weight and underweight). For women, the values ranged from 2.58 cm (non-Hispanic black) to 3.55 cm (normal weight and underweight).

Table D. Mean waist circumference measurement among men, by National Heart, Lung, and Blood Institute and World Health Organization for 2016

Characteristic	N	NHLBI		WHO		Difference (NHLBI minus WHO)		95% confidence interval	
		Mean	SE	Mean	SE	Mean	SE		
Total	1,143	101.02	0.93	100.22	0.95	*0.81	0.13	0.53	1.08
Age group									
20–39	405	96.43	1.50	95.12	1.52	*1.31	0.15	1.00	1.62
40–59	383	102.47	0.74	101.80	0.75	*0.67	0.21	0.22	1.11
60 and over	355	106.24	0.81	106.04	0.87	0.20	0.26	−0.35	0.75
Race and Hispanic origin									
Hispanic	193	100.62	1.85	100.01	1.94	*0.61	0.18	0.24	0.99
Non-Hispanic white	415	101.99	1.24	101.16	1.27	*0.83	0.15	0.50	1.16
Non-Hispanic black	297	99.50	1.22	98.79	1.12	*0.70	0.18	0.32	1.08
Non-Hispanic Asian	189	90.90	0.96	89.91	1.02	*0.99	0.15	0.67	1.31
Obesity category									
Normal weight and underweight	333	84.47	0.60	83.02	0.61	*1.45	0.16	1.12	1.79
Overweight	441	98.37	0.50	97.65	0.63	*0.73	0.18	0.34	1.11
Obese	367	115.96	0.91	115.55	0.88	0.41	0.25	−0.12	0.94

*Significantly different from NHLBI value ($p \leq 0.0125$).

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. WHO is World Health Organization. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table E. Mean waist circumference measurement among women, by National Heart, Lung, and Blood Institute and World Health Organization for 2016

Characteristic	N	NHLBI		WHO		Difference (NHLBI minus WHO)		95% confidence interval	
		Mean	SE	Mean	SE	Mean	SE		
Total	1,154	97.49	1.06	94.29	1.05	*3.21	0.13	2.94	3.48
Age group									
20–39	398	92.54	1.12	89.06	1.07	*3.48	0.15	3.16	3.79
40–59	414	99.80	1.49	96.66	1.58	*3.14	0.25	2.60	3.68
60 and over	342	101.44	1.80	98.55	1.71	*2.89	0.25	2.37	3.42
Race and Hispanic origin									
Hispanic	249	97.89	1.38	95.07	1.26	*2.82	0.23	2.32	3.32
Non-Hispanic white	395	97.47	1.36	94.02	1.37	*3.45	0.17	3.09	3.81
Non-Hispanic black	297	101.72	1.34	99.14	1.19	*2.58	0.23	2.08	3.07
Non-Hispanic Asian	175	85.80	0.79	82.97	0.86	*2.83	0.15	2.50	3.16
Obesity category									
Normal weight and underweight	389	81.68	0.62	78.13	0.64	*3.55	0.14	3.25	3.84
Overweight	297	94.76	0.58	91.65	0.51	*3.11	0.16	2.77	3.45
Obese	468	113.15	1.21	110.19	1.09	*2.97	0.28	2.37	3.56

*Significantly different from NHLBI value ($p \leq 0.0125$).

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. WHO is World Health Organization. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table F. Mean waist circumference measurement among men, by National Heart, Lung, and Blood Institute and Multi-Ethnic Study of Atherosclerosis-Gulick II Plus tape for 2016

Characteristic	N	NHLBI		MESA-Gulick		Difference (NHLBI minus MESA-Gulick)		95% confidence interval	
		Mean	SE	Mean	SE	Mean	SE		
Total	1,143	101.02	0.93	101.70	0.94	*−0.68	0.10	−0.89	−0.47
Age group									
20–39	405	96.43	1.50	97.02	1.63	−0.59	0.21	−1.05	−0.14
40–59	383	102.47	0.74	103.28	0.72	*−0.81	0.12	−1.07	−0.54
60 and over	355	106.24	0.81	106.85	0.75	*−0.61	0.11	−0.85	−0.37
Race and Hispanic origin									
Hispanic	193	100.62	1.85	101.32	1.86	*−0.70	0.18	−1.08	−0.31
Non-Hispanic white	415	101.99	1.24	102.66	1.24	*−0.68	0.10	−0.89	−0.47
Non-Hispanic black	297	99.50	1.22	100.17	1.25	*−0.68	0.12	−0.94	−0.42
Non-Hispanic Asian	189	90.90	0.96	91.41	1.08	−0.51	0.24	−1.01	−0.01
Obesity category									
Normal weight and underweight	333	84.47	0.60	84.94	0.69	−0.46	0.24	−0.98	0.05
Overweight	441	98.37	0.50	99.13	0.51	*−0.75	0.10	−0.97	−0.54
Obese	367	115.96	0.91	116.72	0.90	*−0.76	0.18	−1.15	−0.37

*Significantly different from NHLBI value ($p \le 0.0125$).

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. MESA is Multi-Ethnic Study of Atherosclerosis. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table G. Mean waist circumference measurement among women, by National Heart, Lung, and Blood Institute and Multi-Ethnic Study of Atherosclerosis-Gulick II Plus tape for 2016

Characteristic	N	NHLBI		MESA-Gulick		Difference (NHLBI minus MESA-Gulick)		95% confidence interval	
		Mean	SE	Mean	SE	Mean	SE		
Total	1,154	97.49	1.06	98.38	1.06	−0.89	0.48	−1.91	0.14
Age group									
20–39	398	92.54	1.12	93.30	1.08	−0.76	0.53	−1.89	0.36
40–59	414	99.80	1.49	100.65	1.63	−0.85	0.46	−1.83	0.13
60 and over	342	101.44	1.80	102.57	1.58	−1.13	0.52	−2.25	−0.01
Race and Hispanic origin									
Hispanic	249	97.89	1.38	98.55	1.10	−0.66	0.72	−2.20	0.89
Non-Hispanic white	395	97.47	1.36	98.33	1.42	−0.87	0.52	−1.97	0.24
Non-Hispanic black	297	101.72	1.34	102.85	1.44	−1.13	0.64	−2.49	0.23
Non-Hispanic Asian	175	85.80	0.79	87.02	0.84	−1.22	0.56	−2.42	−0.02
Obesity category									
Normal weight and underweight	389	81.68	0.62	81.88	0.39	−0.20	0.46	−1.17	0.78
Overweight	297	94.76	0.58	95.55	0.56	−0.79	0.58	−2.02	0.44
Obese	468	113.15	1.21	114.70	1.06	*−1.55	0.53	−2.67	−0.43

*Significantly different from NHLBI value ($p \le 0.0125$).

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Tables F and G compare the means of and differences between NHLBI-WC and MESA-WC Gulick. Overall, the mean difference between NHLBI-WC and MESA-WC Gulick was −0.68 cm for men and −0.89 cm for women. Among men, MESA-WC Gulick values were, on average, significantly ($p \le 0.0125$) larger than those of NHLBI in all categories, except normal weight and underweight and age group 20–39. The differences were not significant for women,

except in women who were categorized as being obese. For men, the differences ranged from −0.81 cm (ages 40–59) to −0.46 cm (normal weight and underweight). For women, the differences ranged from −1.55 cm (obese) to −0.20 cm (normal weight and underweight).

Tables H and J compare the average measurement differences between NHLBI-WC and MESA-WC Lufkin. Overall, the

Table H. Mean waist circumference measurement among men, by National Heart, Lung, and Blood Institute and Multi-Ethnic Study of Atherosclerosis-Lufkin tape for 2016

Characteristic	N	NHLBI Mean	NHLBI SE	MESA-Lufkin Mean	MESA-Lufkin SE	Difference (NHLBI minus MESA-Lufkin) Mean	Difference (NHLBI minus MESA-Lufkin) SE	95% confidence interval	
Total	1,143	101.02	0.93	101.01	0.96	0.02	0.08	−0.16	0.19
Age group									
20–39	405	96.43	1.50	96.29	1.61	0.14	0.19	−0.26	0.53
40–59	383	102.47	0.74	102.53	0.75	−0.06	0.14	−0.35	0.23
60 and over	355	106.24	0.81	106.30	0.79	−0.06	0.08	−0.24	0.12
Race and Hispanic origin									
Hispanic	193	100.62	1.85	100.57	1.81	0.05	0.18	−0.33	0.44
Non-Hispanic white	415	101.99	1.24	101.98	1.27	0.01	0.09	−0.19	0.21
Non-Hispanic black	297	99.50	1.22	99.56	1.22	−0.07	0.09	−0.26	0.12
Non-Hispanic Asian	189	90.90	0.96	90.75	1.06	0.15	0.19	−0.25	0.56
Obesity category									
Normal weight and underweight	333	84.47	0.60	84.21	0.68	0.27	0.24	−0.24	0.77
Overweight	441	98.37	0.50	98.43	0.49	−0.06	0.10	−0.27	0.14
Obese	367	115.96	0.91	116.04	0.90	−0.08	0.15	−0.41	0.25

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. MESA is Multi-Ethnic Study of Atherosclerosis. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table J. Mean waist circumference measurement among women, by National Heart, Lung, and Blood Institute and Multi-Ethnic Study of Atherosclerosis-Lufkin tape for 2016

Characteristic	N	NHLBI Mean	NHLBI SE	MESA-Lufkin Mean	MESA-Lufkin SE	Difference (NHLBI minus MESA-Lufkin) Mean	Difference (NHLBI minus MESA-Lufkin) SE	95% confidence interval	
Total	1,154	97.49	1.06	97.42	1.03	0.08	0.44	−0.86	1.02
Age group									
20–39	398	92.54	1.12	92.29	1.08	0.25	0.44	−0.69	1.20
40–59	414	99.80	1.49	99.78	1.61	0.02	0.44	−0.91	0.95
60 and over	342	101.44	1.80	101.54	1.49	−0.10	0.56	−1.30	1.10
Race and Hispanic origin									
Hispanic	249	97.89	1.38	97.80	1.09	0.09	0.68	−1.37	1.55
Non-Hispanic white	395	97.47	1.36	97.32	1.40	0.14	0.49	−0.90	1.19
Non-Hispanic black	297	101.72	1.34	101.86	1.43	−0.14	0.49	−1.18	0.91
Non-Hispanic Asian	175	85.80	0.79	86.19	0.80	−0.39	0.51	−1.49	0.70
Obesity category									
Normal weight and underweight	389	81.68	0.62	80.95	0.40	0.72	0.39	−0.11	1.55
Overweight	297	94.76	0.58	94.58	0.58	0.18	0.55	−0.99	1.36
Obese	468	113.15	1.21	113.72	1.04	−0.56	0.52	−1.67	0.54

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. MESA is Multi-Ethnic Study of Atherosclerosis. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

difference between the two measurements was 0.02 cm for men and 0.08 cm for women. None of the differences was statistically significant. In men, the differences ranged from 0.01 cm (non-Hispanic white) to 0.27 cm (normal weight and underweight). For women, the differences ranged from −0.56 cm (obese) to 0.72 cm (normal weight and underweight).

Tables K and M compare the measurement differences between the NHLBI-WC and MESA-assisted over clothes measurements. Overall, the difference was −0.71 cm for men and 1.34 cm for women. In men, the difference was statistically significant for those who were aged 20–39 and 40–59, non-Hispanic white, non-Hispanic black, non-Hispanic Asian, normal weight and underweight and overweight. In women, the difference was statistically significant for those who were aged 60 and over, Hispanic, and those with obesity. For men, the values of the difference in the two measurements ranged from −1.74 cm (normal weight and underweight) to −0.03 cm (aged 60 and over). For women,

Table K. Mean waist circumference measured over clothes among men, by National Heart, Lung, and Blood Institute and Multi-Ethnic Study of Atherosclerosis-assisted measurement for 2016

Characteristic	N	NHLBI		MESA-assisted		Difference (NHLBI minus MESA-assisted)		95% confidence interval	
		Mean	SE	Mean	SE	Mean	SE		
Total	1,143	101.02	0.93	101.73	0.94	*−0.71	0.13	−0.98	−0.44
Age group									
20–39	405	96.43	1.50	97.52	1.56	*−1.09	0.15	−1.42	−0.77
40–59	383	102.47	0.74	103.20	0.75	*−0.73	0.24	−1.26	−0.21
60 and over	355	106.24	0.81	106.28	0.84	−0.03	0.27	−0.62	0.55
Race and Hispanic origin									
Hispanic	193	100.62	1.85	100.96	1.72	−0.34	0.29	−0.96	0.28
Non-Hispanic white	415	101.99	1.24	102.64	1.23	*−0.65	0.18	−1.03	−0.27
Non-Hispanic black	297	99.50	1.22	100.97	1.22	*−1.47	0.20	−1.90	−1.05
Non-Hispanic Asian	189	90.90	0.96	92.04	0.97	*−1.14	0.27	−1.71	−0.56
Obesity category									
Normal weight and underweight	333	84.47	0.60	86.22	0.74	*−1.74	0.29	−2.37	−1.12
Overweight	441	98.37	0.50	99.00	0.47	*−0.63	0.15	−0.95	−0.31
Obese	367	115.96	0.91	116.00	0.94	−0.04	0.26	−0.60	0.51

*Significantly different from NHLBI value ($p \leq 0.0125$).

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. MESA is Multi-Ethnic Study of Atherosclerosis. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Table M. Mean waist circumference measured over clothes among women, by National Heart, Lung, and Blood Institute and Multi-Ethnic Study of Atherosclerosis-assisted measurement for 2016

Characteristic	N	NHLBI		MESA-assisted		Difference (NHLBI minus MESA-assisted)		95% confidence interval	
		Mean	SE	Mean	SE	Mean	SE		
Total	1,154	97.49	1.06	96.15	0.99	*1.34	0.45	0.39	2.29
Age group									
20–39	398	92.54	1.12	91.49	0.97	1.05	0.56	−0.15	2.25
40–59	414	99.80	1.49	98.61	1.56	1.19	0.47	0.19	2.20
60 and over	342	101.44	1.80	99.42	1.55	*2.02	0.48	1.01	3.04
Race and Hispanic origin									
Hispanic	249	97.89	1.38	95.38	1.41	*2.51	0.65	1.13	3.90
Non-Hispanic white	395	97.47	1.36	96.17	1.40	1.30	0.56	0.10	2.50
Non-Hispanic black	297	101.72	1.34	100.53	1.54	1.19	0.78	−0.47	2.85
Non-Hispanic Asian	175	85.80	0.79	86.01	0.86	−0.21	0.97	−2.27	1.85
Obesity category									
Normal weight and underweight	389	81.68	0.62	80.66	0.44	1.01	0.49	−0.03	2.06
Overweight	297	94.76	0.58	93.60	0.66	1.16	0.61	−0.15	2.46
Obese	468	113.15	1.21	111.41	1.02	*1.74	0.54	0.60	2.88

*Significantly different from NHLBI value ($p \leq 0.0125$).

NOTES: N is number of subjects measured. NHLBI is National Heart, Lung, and Blood Institute. MESA is Multi-Ethnic Study of Atherosclerosis. SE is standard error.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

the differences ranged from −0.21 cm (non-Hispanic Asian) to 2.51 cm (Hispanic).

Table N shows the sensitivity and specificity of abdominal obesity by sex, using NHLBI-WC as the reference. Men had higher sensitivity and specificity values for all measurements compared with those of women, except specificity values for WHO-WC. In men, MESA-WC Gulick had the highest sensitivity (99.0%) and WHO-WC had the lowest sensitivity (94.2%); WHO-WC had the highest specificity (96.2%) and MESA-assisted had the lowest specificity (92.8%). In women, MESA-WC Gulick had the highest sensitivity (93.9%) and WHO-WC had the lowest sensitivity (86.7%); WHO-WC had the highest specificity (99.6%) and MESA-WC Gulick had the lowest specificity (86.2%).

Table N. Sensitivity and specificity of abdominal obesity defined by National Heart, Lung, and Blood Institute-waist circumference and other protocols

Sex	WHO		MESA-Gulick		MESA-Lufkin		MESA-assisted	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
Male	94.2	96.2	99.0	94.5	96.6	95.7	94.8	92.8
Female	86.7	99.6	93.9	86.2	92.8	92.7	89.7	90.4

NOTES: WHO is the World Health Organization. MESA is Multi-Ethnic Study of Atherosclerosis.

SOURCE: NCHS, National Health and Nutrition Examination Survey, 2016.

Discussion

The study compared four alternative protocols to measure WC (WHO, MESA with Gulick, MESA with Lufkin, and MESA-assisted) with the NHLBI-WC, the reference standard protocol (5–8).

Most results fell within NHANES internal established tolerance limits using the NHLBI-WC method (tolerance criteria of ±1.5 cm) as a cut point. The difference between other protocols and the reference NHLBI-WC was less than 1.5 cm for all comparisons except MESA-assisted (normal weight men, women aged 60 and over, Hispanic women, and women with obesity), MESA-Gulick (women with obesity), and NHLBI-WC and WHO-WC, where all of the differences for women were well over 1.5. Similar differences between the WHO-WC protocol and the NHLBI-WC protocol among women were reported elsewhere and have been attributed to differences in male and female anatomy (18,19).

All methods had a sensitivity of 90% to 99%, except WHO-WC for women, meaning that more than 90% of subjects classified by NHLBI-WC as having abdominal obesity were also classified as having abdominal obesity using WC from other protocols. Similarly, all methods had a specificity of 90% to 99%, except MESA-WC using Gulick II Plus tape for women, meaning that more than 90% subjects not classified as abdominal obesity by NHLBI-WC were also not classified as abdominal obesity using WC from other protocols.

Among men, the WC measurements using the other four alternative protocols were close to those of the NHLBI-WC measurements; as a result, sensitivity and specificity were above 90% for all these methods. However, among women, mean WHO-WC was 3.19 cm 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 NHLBI-WC had a lower chance to be classified as having abdominal obesity using WHO-WC since the latter was measured 3 cm lower on average. This also means that a woman who did not meet the criteria for abdominal obesity based on the NHLBI measurement would likely be classified as not having obesity based on WHO-WC. The low specificity of MESA-WC using Gulick II Plus tape among women (85.88%) was possibly due to MESA-WC measuring higher than NHLBI-WC, specifically among the obese group (1.51 cm higher). As a result, women who had WC close to 88 cm and were not classified as having abdominal obesity using NHLBI-WC were still likely to be classified as having abdominal obesity with MESA-WC using Gulick II Plus tape.

Some recent studies compared WC measurement protocols. Statistics Canada used both the WHO-WC and the NHLBI-WC methods during a recent 2-year survey cycle for a subsample of adult men (n = 824) and women (n = 908) aged 20–79. The Canadian study showed that men had a smaller difference in WC (0.8 cm) than women (2.2 cm). Similar to the results in this report, obesity was associated with increased differences in WC, more so in women than in men (1.7 cm and 0.3 cm, respectively) (19). Mason and Katzmarzyk compared WHO-WC and NHLBI-WC methods using a convenient sample of men (n = 223) and women (319). Their results showed that, similar to the current study and Canadian study, men had a smaller difference in WC (0.3 cm) than women (2.1 cm) (18).

The strength of this analysis is the use of NHANES' 1-year nationally representative sample of participants aged 20 and over. Power for testing the differences between the two measurements was high (power greater than 0.99 for men; power greater than 0.9 for women except the MESA-Gulick method, where power = 0.89) based on the power analysis using variance estimates from the current WC study, assuming a mean difference of 1.5 cm between two measurements (NHLBI compared with another protocol). Besides following standardized WC measuring protocols, the reliability of these WC measurements (except MESA-assisted) was evaluated by a reference evaluator, who had obtained interobserver reliability with HT.

The findings in this study are subject to several limitations. First, the MESA-assisted measures were obtained in the NHANES MEC and may not be generalizable to conducting them in the participants' homes. Second, while the NHLBI-WC measurements were taken at the MEC by the HTs and were evaluated by a reference interevaluator, no such reliability measure was available for the MESA-assisted WC measurements, other than observation of the HT.

This study compared four alternative protocols for measuring waist circumference to the reference NHLBI protocol. Generally, differences were minimal between the protocols with a few exceptions. These results, based on a large representative sample of the U.S. noninstitutionalized population aged 20 and over, may inform future studies that aim to use other WC measurement protocols.

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