Measures of Adiposity and Cardiovascular Disease Risk Factors

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Abstract

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Objective: To determine which of five measures of adiposity maintains the strongest association with cardiovascular disease risk factors.

Research Methods and Procedures: A nationally representative sample of 12,608 adult participants of the third National Health and Nutrition Examination Survey were examined. Waist circumference, total body fat, percent body fat, BMI, and skinfold thickness were measured following a standardized protocol.

Results: In multivariable adjusted models including waist circumference and BMI as independent variables, waist circumference was a significantly better predictor. The odds ratios (95% confidence intervals) for each standard deviation higher waist circumference and BMI for men were as follows: 1.88 (1.43, 2.48) and 0.99 (0.76, 1.29), respectively, for hypertension; 1.51 (0.87, 2.59) and 1.23 (0.76, 1.99), respectively, for diabetes; and 1.85 (1.48, 2.32) and 1.00 (0.80, 1.24), respectively, for low high-density lipoprotein-cholesterol. The analogous odds ratios (95% confidence intervals) for women were as follows: 2.28 (1.74, 3.00) and 0.91 (0.69, 1.19), respectively, for hypertension; 2.72 (1.85, 4.00) and 0.82 (0.55, 1.23), respectively, for diabetes; and 1.90 (1.47, 2.47) and 1.07 (0.83, 1.38), respectively, for low high-density lipoprotein-cholesterol. Results were markedly similar for waist circumference in models adjusting for total body fat, percent body fat, and skinfold thickness separately. In contrast, waist circumference was not a significantly better predictor of elevated C-reactive protein than the other measures of adiposity.

Discussion: Waist circumference maintains a stronger association with cardiovascular disease risk factors than other measures of adiposity.

Key words: abdominal fat, adiposity, anthropometry, bioelectrical impedance analysis, National Health and Nutrition Examination Survey

Introduction

Higher adiposity has been shown in several previous studies to be associated with an increased risk of cardiovascular disease and stroke morbidity and mortality (1–3). BMI is a frequently used measure of adiposity in both clinical and research settings. However, waist circumference has been used as a measure of abdominal adiposity in research settings and has shown stronger associations with cardiovascular disease risk factors than BMI (4–7). Skinfold thickness is also used as a measure of adiposity, but studies comparing its predictive ability to other measures of adiposity have produced inconsistent findings (8–12). An additional measure of adiposity is bioelectrical impedance analysis (BIA),[1] which can be used to estimate an individual's total body fat (TBF) and percentage body fat (%BF). However, whether TBF and %BF maintain stronger associations with cardiovascular disease risk factors compared with simpler measures, such as BMI or waist circumference, remains unknown (13–16).

The purpose of this analysis was to assess which of five measures of adiposity (waist circumference, BMI, TBF, %BF, or skinfold thickness) maintains the strongest association with cardiovascular disease risk factors. To do so, we analyzed the association of these measures with hypertension, diabetes, elevated C-reactive protein (CRP), and low

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[1] Nonstandard abbreviations: BIA, bioelectrical impedance analysis; TBF, total body fat; %BF, percentage body fat; CRP, C-reactive protein; HDL, high-density lipoprotein; NHANES III, the third National Health and Nutrition Examination Survey; HOMA-IR, homeostasis model analysis insulin resistance; LDL, low-density lipoprotein; Val res, Valhalla resistance value; RJL res, RJL resistance value; FFM, fat free mass; OR, odds ratio.

high-density lipoprotein (HDL)-cholesterol in a nationally representative sample of adults in the United States using data from the third National Health and Nutrition Examination Survey (NHANES III). Additionally, we assessed the association of each measure of adiposity with elevated homeostasis model analysis insulin resistance (HOMA-IR), elevated triglycerides, and high low-density lipoprotein (LDL)-cholesterol in the subgroup of NHANES III participants who fasted 9 or more hours before their study visit.

Research Methods and Procedures

Study Population

NHANES III was a cross-sectional survey of the civilian, non-institutionalized, U.S. population conducted from 1988 to 1994 (17). After excluding 288 women who were pregnant and 3677 participants with missing data, the final sample for the current set of analyses included 12,608 NHANES III participants ≥20 years of age. Among the subgroup of participants who were assigned to a morning examination and fasted 9 or more hours before their study visit, 5550 had complete data and were included in the subgroup analyses.

Data Collection

The NHANES III data were collected during an in-home interview and a subsequent visit to a mobile examination center (17). During the in-home interview, demographic information including age, race, and sex was collected using a standardized questionnaire. Additional data collected during the in-home interview that are relevant to this analysis included anti-hypertensive, anti-diabetes, and cholesterol-lowering medication use, cigarette smoking, alcohol consumption, and physical activity.

Adiposity Measures

Five measures of adiposity were analyzed, including waist circumference, BMI, TBF, %BF, and skinfold thickness. Waist circumference was measured at the iliac crest to the nearest 0.1 cm. Height was measured with a stadiometer. Weight was measured with an electronic digital scale while the participant was wearing foam slippers and paper shirt and pants. Height and weight measurements, used to calculate BMI (weight in kilograms divided by height in meters squared), were obtained to the nearest 0.1 cm and 0.01 kg, respectively.

A Valhalla Scientific Body Composition Analyzer (model 1990B; Valhalla Scientific, Inc., San Diego, CA) was used to measure whole body electrical resistance (Val res). Prediction equations were used to convert whole body electrical resistance at 50 kHz to TBF and %BF. Because the available prediction equations are based on data from an RJL bioelectrical impedance analyzer (RJL Systems, Inc., Clinton Twp., MI), Val res first had to be converted to RJL resistance values (RJL res) using the following equations (18):

$$\text{RJL res (ohms)} = [2.5 + 0.98 \times \text{Val res (ohms)}] \text{ for men} \quad (1)$$

$$\text{RJL res (ohms)} = [9.6 + 0.96 \times \text{Val res (ohms)}] \text{ for women} \quad (2)$$

Next, fat-free mass (FFM) was calculated as:

$$\text{FFM (kg)} = \{-10.678 + 0.262 \times \text{weight (kg)} + [0.652 \times \text{height}^2 \text{ (cm)/RJL res (ohms)}] + 0.015 \text{ RJL res (ohms)}\} \text{ for men} \quad (3)$$

$$\text{FFM (kg)} = \{-9.529 + 0.168 \times \text{weight (kg)} + [0.696 \times \text{height}^2 \text{ (cm)/RJL res (ohms)}] + 0.016 \text{ RJL res (ohms)}\} \text{ for women} \quad (4)$$

TBF and %BF were calculated using the following equations:

$$\text{TBF (kg)} = \text{weight (kg)} - \text{FFM (kg)} \quad (5)$$

$$\%\text{ BF} = \text{TBF (kg)/weight (kg)} \quad (6)$$

Skinfold thickness was measured to the nearest 0.1 mm using skinfold calipers. Thigh, triceps, subscapular, and suprailiac skinfold measurements were taken twice on the right side of the participant's body and averaged. Skinfold thicknesses larger than the caliper could measure were considered 1 mm bigger than the largest respective measured value (n = 1014 for thigh; n = 173 for triceps; n = 253 for subscapular; n = 341 for suprailiac). The four skinfold thickness measurements were summed to create a total skinfold value that was used for this analysis.

Cardiovascular Risk Factor Measures

Four cardiovascular disease risk factors were analyzed as primary outcomes (hypertension, diabetes, elevated CRP, and low HDL-cholesterol), with three additional outcomes (elevated HOMA-IR, elevated triglycerides, and high LDL-cholesterol) analyzed in the subgroup of NHANES III participants who attended the morning examination session and fasted for 9 or more hours.

As previously described, blood pressure was measured six times following a protocol adapted from the American Heart Association (17). Based on an average of all six blood pressure measurements, hypertension was defined as systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg and/or current use of blood pressure–lowering medication.

During the visit to the mobile examination center, a blood specimen was drawn from the participant's antecubital vein by a trained phlebotomist according to a standardized protocol (17). Plasma glucose was measured using an enzymatic reaction. Diabetes was defined as plasma glucose ≥200 mg/dL for participants who did not fast for 9 or more hours (≥126 mg/dL for participants who fasted ≥9 hours) and/or a self-reported history of diabetes with concurrent use of anti-diabetes medication.

Serum CRP was quantified using latex-enhanced nephelometry (17). Elevated CRP was defined as serum CRP ≥1.0 mg/dL. HDL-cholesterol was measured after the precipitation of the other lipoprotein/divalent cation mixture, and low HDL-cholesterol was defined as <40 mg/dL for men and <50 mg/dL for women. Serum triglycerides were measured enzymatically, and elevated triglycerides was defined as ≥150 mg/dL. LDL-cholesterol values were calculated for participants with triglycerides <400 mg/dL using the Freidewald equation (19). High LDL-cholesterol was defined as ≥130 mg/dL. Insulin radioimmunoassay was used to measure serum insulin (17). HOMA-IR was calculated using the equation (20):

$$\text{HOMA-IR} = \text{insulin (mU/liter)} \times \text{glucose (mM)}/22.5 \quad (7)$$

Participants with HOMA-IR ≥3.0 were considered to have elevated HOMA-IR.

Statistical Methods

Because of a consistently significant sex interaction with all outcomes and the different degree of adiposity among men and women, all analyses were performed stratified by sex. Correlation coefficients were calculated for waist circumference, BMI, TBF, %BF, and skinfold thickness. Next, in accordance with Adult Treatment Panel III guidelines, participants with a waist circumference >102 cm for men and >88 cm for women were defined as having abdominal obesity (21). Participants with a BMI ≥30 kg/m^2 were defined as being obese. Participants in the highest quartile of TBF (≥24.0 kg for men and ≥30.4 kg for women), %BF (≥27.6% for men and ≥40.1% for women), and skinfold thickness (≥83.7 mm for men and ≥120.3 mm for women) were defined as having high TBF, high %BF, and high skinfold thickness, respectively. The age-adjusted prevalence of hypertension, diabetes, elevated CRP, and low HDL-cholesterol were calculated for persons with and without abdominal obesity, obesity, high TBF, high %BF, and high skinfold thickness.

Next, waist circumference, BMI, TBF, %BF, and skinfold thickness were divided into sex-specific population quartiles. The odds ratios (ORs) of hypertension, diabetes, elevated CRP and low HDL-cholesterol associated with quartiles of each measure of adiposity were determined after multivariable adjustment using logistic regression, with the lowest quartile serving as the reference category. All odds ratios were adjusted for age, race-ethnicity, high school education, alcohol consumption, physical inactivity, current and former smoking, and two measures of adiposity simultaneously (e.g., waist circumference and TBF) as independent variables. Logistic regression models with quartile of adiposity measures included as continuous variables were used to assess linear trends in the adjusted OR of each outcome. Subsequent models additionally included quartile of adiposity squared to assess curvilinear trends in the adjusted OR of each outcome. Next, the multivariable adjusted ORs of hypertension, diabetes, elevated CRP, and low HDL-cholesterol associated with a 1 standard deviation higher waist circumference, BMI, TBF, %BF, and skinfold thickness were determined using logistic regression models. The statistical significance of the difference between waist circumference and the other measure of adiposity in each model was calculated.

Subgroup analyses that included the 5550 participants who attended the morning examination session and fasted at least 9 hours were conducted to determine the multivariable adjusted ORs of elevated HOMA-IR, elevated serum triglycerides, and high LDL-cholesterol associated with a 1 standard deviation higher waist circumference, BMI, TBF, %BF, and skinfold thickness. All analyses were repeated after stratification by race-ethnicity with markedly similar results in each race-ethnicity group (data not shown).

All data were analyzed using SUDAAN (version 9.0; Research Triangle Institute, Research Triangle Park, NC), accounting for the complex NHANES sampling design. All analyses incorporated sampling weights and units of sampling (i.e., strata and primary sampling units) that adjusted for unequal probabilities of selection, oversampling, and non-response.

Results

The sex-specific correlation coefficients between each measure of adiposity are presented in Table 1. Among both men and women, the measures of adiposity maintained high correlations with each other (all $p < 0.001$).

The age-adjusted prevalence of hypertension, diabetes, and low HDL-cholesterol was higher for men with abdominal obesity, obesity, high TBF, high %BF, and high skinfold thickness compared with men without these conditions (Table 2, top panel). The age-adjusted prevalence of elevated CRP was only higher among men with high %BF and high skinfold thickness. The age-adjusted prevalence of each cardiovascular disease risk factor was higher among women with abdominal obesity, obesity, high TBF, high %BF, and high skinfold thickness compared with women without these conditions (Table 2, bottom panel).

Higher quartiles of waist circumference were associated with higher ORs of hypertension, diabetes, and low HDL-cholesterol after adjustment for each measure of adiposity separately (Table 3; each $p < 0.001$). As noted in Table 3, several of these trends were curvilinear. After adjustment for other adiposity measures, larger waist circumference

Table 1. Correlation coefficients* between measures of adiposity among NHANES III participants

	Skinfold thickness	%BF	TBF	BMI	Waist circumference
Men (n = 6197)					
Waist circumference	0.779	0.688	0.866	0.894	1.000
BMI	0.798	0.645	0.869	1.000	
TBF	0.800	0.883	1.000		
%BF	0.662	1.000			
Skinfold thickness	1.000				
Women (n = 6411)					
Waist circumference	0.785	0.805	0.883	0.885	1.000
BMI	0.856	0.835	0.951	1.000	
TBF	0.864	0.905	1.000		
%BF	0.827	1.000			
Skinfold thickness	1.000				

NHANES III, the Third National Health and Nutrition Examination Survey; %BF, percentage body fat; TBF, total body fat.
* $p < 0.001$ between all measures of adiposity.

was not associated with elevated CRP among men (except in the model that adjusted for BMI; $p = 0.037$). Higher levels of BMI, TBF, %BF, and skinfold thickness were not associated with an increased OR of hypertension, diabetes, elevated CRP, or low HDL-cholesterol after adjustment for waist circumference [except for the associations of %BF with hypertension and elevated CRP (each $p < 0.05$) and BMI with low HDL-cholesterol ($p = 0.005$)].

Among women, higher quartiles of waist circumference were associated with higher multivariable adjusted ORs of hypertension, diabetes, elevated CRP, and low HDL-cholesterol (Table 4; each $p < 0.01$). Each higher quartile of waist circumference was associated with a progressively higher OR of each outcome, with some of these trends being curvilinear. After adjustment for waist circumference, higher quartiles of BMI, TBF, %BF, and skinfold thickness were associated with increased multivariable adjusted ORs of elevated CRP (each $p < 0$ .05); they were not associated with increased ORs of hypertension, diabetes, or low HDL-cholesterol. A trend of lower odds of diabetes at higher TBF and %BF was present after adjustment for waist circumference.

Table 5 shows results of multivariable adjusted models including waist circumference and one alternative measure of adiposity as standardized continuous variables. Among men and women, waist circumference maintained a significantly stronger association with hypertension, diabetes, and low HDL-cholesterol than BMI, TBF, %BF, and skinfold thickness (except for diabetes when adjusted for BMI among men). In contrast, waist circumference was not a statistically significantly better predictor of elevated CRP than BMI, TBF, %BF, or skinfold thickness.

The OR of hypertension associated with waist circumference was higher at lower age categories, and waist circumference was not a significantly better predictor of hypertension than the other measures of adiposity in the 75-year and older age group (data not shown; all p values for interaction <0.001). Among women, the OR of diabetes associated with waist circumference was higher for non-Hispanic whites than for non-Hispanic blacks or Mexican Americans. However, in all race-ethnicity groups, waist circumference maintained a significantly stronger association with diabetes than BMI, TBF, %BF, and skinfold thickness.

Among men and women, in multivariable adjusted models including two standardized measures of adiposity simultaneously, waist circumference maintained a significantly stronger association with elevated HOMA-IR and elevated triglycerides than BMI, TBF, %BF, and skinfold thickness (Table 6). In contrast, waist circumference was not a better predictor of high LDL-cholesterol than BMI, %BF, or skinfold thickness. Although these associations were observed in all subgroups studied, the ORs of elevated HOMA-IR were consistently higher for non-Hispanic whites than for non-Hispanic blacks or Mexican Americans (data not shown; all p values for interaction <0.05).

Discussion

The purpose of this analysis was to study which measure of adiposity (waist circumference, BMI, TBF, %BF, or skinfold thickness) maintains the strongest association with cardiovascular disease risk factors in a nationally representative sample of U.S. adults. In our analyses, waist circumference was consistently a better predictor of hypertension,

Table 2. Age-adjusted* prevalence (standard error) of hypertension, diabetes, elevated CRP, and low HDL-cholesterol by abdominal obesity, obesity, high TBF, high %BF, and high skinfold thickness category among NHANES III participants

	Hypertension†	Diabetes‡	Elevated CRP§	Low HDL-cholesterol¶
Men (n = 6197)				
Waist circumference ≤102 cm	21.6 (0.8)	3.7 (0.4)	4.4 (0.4)	28.4 (1.3)
Waist circumference >102 cm	36.6 (2.2)‡‡	10.8 (0.7)‡‡	5.9 (0.9)	50.8 (3.0)‡‡
BMI <30 kg/m^2	22.3 (0.8)	4.6 (0.4)	4.7 (0.5)	31.0 (1.1)
BMI ≥30 kg/m^2	40.7 (2.8)‡‡	12.9 (1.4)‡‡	5.6 (1.0)	50.8 (3.1)‡‡
TBF <24.0 kg	21.8 (0.7)	4.5 (0.5)	4.7 (0.5)	30.3 (1.1)
TBF ≥24.0 kg	35.6 (2.3)‡‡	11.2 (1.3)‡‡	5.3 (0.8)	46.0 (3.0)‡‡
%BF <27.6%	22.6 (0.7)	5.6 (0.5)	3.8 (0.5)	31.8 (1.2)
%BF ≥27.6%	33.7 (2.1)‡‡	8.1 (0.7)††	7.8 (0.9)‡‡	42.0 (2.5)‡‡
Skinfold thickness <83.7 mm	23.5 (0.8)	5.0 (0.4)	4.4 (0.4)	31.2 (1.2)
Skinfold thickness ≥83.7 mm	30.7 (2.7)††	10.4 (1.1)‡‡	6.3 (0.9)**	44.2 (2.4)‡‡
Women (n = 6411)				
Waist circumference ≤88 cm	16.5 (0.7)	1.6 (0.3)	4.5 (0.5)	26.5 (1.8)
Waist circumference >88 cm	31.9 (1.0)‡‡	7.4 (0.7)‡‡	15.6 (1.3)‡‡	51.9 (1.5)‡‡
BMI <30 kg/m^2	20.4 (0.7)	3.1 (0.3)	5.6 (0.5)	31.2 (1.4)
BMI ≥30 kg/m^2	35.2 (1.6)‡‡	9.3 (0.9)‡‡	21.3 (1.4)‡‡	57.5 (1.6)‡‡
TBF <30.4 kg	19.8 (0.7)	3.1 (0.3)	5.6 (0.5)	30.9 (1.5)
TBF ≥30.4 kg	34.7 (1.2)‡‡	8.6 (0.8)‡‡	19.0 (1.3)‡‡	54.7 (1.8)‡‡
%BF <40.1%	20.2 (0.7)	3.8 (0.5)	5.7 (0.6)	31.9 (1.5)
%BF ≥40.1%	33.4 (1.4)‡‡	6.5 (0.7)‡‡	19.0 (1.2)‡‡	52.3 (2.0)‡‡
Skinfold thickness <120.3 mm	20.4 (0.7)	3.4 (0.3)	5.7 (0.5)	31.2 (1.5)
Skinfold thickness ≥120.3 mm	31.9 (1.4)‡‡	7.7 (0.8)‡‡	18.2 (1.3)‡‡	52.9 (1.8)‡‡

CRP, C-reactive protein; HDL, high-density lipoprotein; TBF, total body fat; %BF, percentage body fat; NHANES III, the Third National Health and Nutrition Examination Survey;.

* Adjusted to the age distribution of the 2000 U.S. population.

† Systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg and/or use of anti-hypertensive medication.

‡ Fasting glucose ≥126 mg/dL or non-fasting glucose ≥200 mg/dL and/or use of anti-diabetes medication.

§ Serum CRP ≥1.0 mg/dL.

¶ HDL-cholesterol <40 mg/dL for men or <50 or mg/dL for women.

** $p < 0.05$; †† $p < 0.01$; and ‡‡ $p < 0.001$ for a higher prevalence of the outcome among those with high compared with low category of adiposity.

diabetes, low HDL-cholesterol, elevated HOMA-IR, and elevated triglycerides among both men and women.

To our knowledge, this is the first study to compare waist circumference with four other measures of adiposity, including BMI, TBF, %BF, and skinfold thickness, as predictors of cardiovascular disease risk factors in a nationally representative sample of U.S. adults. Our results are consistent with previous studies that report anthropometric measures that take into account the distribution of adiposity, specifically abdominal adiposity (i.e., waist circumference or waist-to-hip ratio), and maintain a stronger association with cardiovascular disease risk factors than BMI (4–7,11,12). However, few studies have compared multiple measures of adiposity (14,22). In a previous cross-sectional study of 782 persons, waist circumference was found to be a stronger predictor of total cholesterol and basal blood glucose than BMI, waist-to-hip ratio, subscapular-to-tricipital skinfold thickness, and %BF. While waist-to-hip ratio was found to be a stronger predictor of HDL-cholesterol and triglycerides, BMI was found to be a stronger predictor of blood pressure, and %BF was found to be a stronger predictor of postprandial blood glucose (22). Additionally, in a study of 1293 men, quartile of TBF remained associated with HDL-cholesterol, HDL-total cholesterol ratio, triglyc-

Table 3. Multivariable adjusted* odds ratios (95% confidence interval) of hypertension, diabetes, elevated CRP, and low HDL-cholesterol associated with quartiles of two measures of adiposity† among men

	Quartile 1	Quartile 2	Quartile 3	Quartile 4	*p* value for linear trend	*p* value for curvilinear trend
Hypertension‡						
Waist circumference	1.00	1.96 (1.37, 2.81)	3.30 (2.11, 5.17)	4.21 (2.38, 7.46)	<0.001	0.022
BMI	1.00	0.88 (0.66, 1.18)	0.78 (0.52, 1.17)	1.24 (0.75, 2.03)	0.295	
Waist circumference	1.00	1.83 (1.27, 2.66)	3.18 (2.15, 4.72)	4.63 (3.08, 6.96)	<0.001	
TBF	1.00	1.12 (0.74, 1.70)	0.81 (0.55, 1.18)	1.17 (0.78, 1.77)	0.738	
Waist circumference	1.00	1.64 (1.20, 2.25)	2.54 (1.83, 3.52)	3.78 (2.67, 5.37)	<0.001	
%BF	1.00	1.03 (0.75, 1.42)	1.40 (0.98, 1.99)	1.44 (0.99, 2.10)	0.041	
Waist circumference	1.00	2.24 (1.44, 3.46)	4.32 (2.53, 7.37)	7.53 (4.20, 13.5)	<0.001	
Skinfold	1.00	0.72 (0.46, 1.14)	0.57 (0.34, 0.93)	0.60 (0.35, 1.03)	0.087	
Diabetes§						
Waist circumference	1.00	1.18 (0.77, 1.80)	1.37 (0.66, 2.82)	3.62 (1.76, 7.43)	<0.001	0.009
BMI	1.00	0.71 (0.39, 1.30)	0.94 (0.55, 1.60)	1.13 (0.56, 2.28)	0.357	
Waist circumference	1.00	1.55 (0.96, 2.52)	2.24 (0.96, 5.25)	5.97 (2.52, 14.1)	<0.001	
TBF	1.00	0.43 (0.24, 0.77)	0.45 (0.20, 1.00)	0.67 (0.027, 1.66)	0.996	
Waist circumference	1.00	1.21 (0.75, 1.95)	1.59 (0.84, 3.00)	5.32 (3.02, 9.38)	<0.001	0.001
%BF	1.00	0.60 (0.36, 0.99)	0.88 (0.48, 1.61)	0.61 (0.36, 1.05)	0.230	
Waist circumference	1.00	1.00 (0.61, 1.65)	1.19 (0.62, 2.27)	3.50 (2.01, 6.08)	<0.001	0.003
Skinfold	1.00	1.23 (0.69, 2.20)	1.05 (0.60, 1.83)	1.39 (0.72, 2.66)	0.394	
Elevated CRP¶						
Waist circumference	1.00	1.95 (1.01, 3.76)	2.09 (0.82, 5.34)	3.49 (1.19, 10.2)	0.037	
BMI	1.00	0.93 (0.42, 2.05)	0.79 (0.36, 1.75)	0.68 (0.24, 1.93)	0.417	
Waist circumference	1.00	1.44 (0.74, 2.81)	1.22 (0.48, 3.12)	1.93 (0.67, 5.58)	0.304	
TBF	1.00	1.35 (0.66, 2.73)	1.78 (0.86, 3.69)	1.25 (0.48, 3.24)	0.652	
Waist circumference	1.00	1.60 (0.85, 3.03)	1.35 (0.66, 2.77)	1.55 (0.72, 3.32)	0.480	
%BF	1.00	1.13 (0.65, 1.98)	0.90 (0.53, 1.54)	2.12 (1.12, 4.00)	0.026	0.041
Waist circumference	1.00	1.69 (0.90, 3.16)	1.44 (0.64, 3.25)	1.80 (0.75, 4.30)	0.381	
Skinfold	1.00	0.94 (0.59, 1.51)	1.14 (0.56, 2.35)	1.54 (0.69, 3.47)	0.226	
Low HDL-cholesterol**						
Waist circumference	1.00	1.40 (0.95, 2.05)	2.27 (1.59, 3.24)	3.27 (2.16, 4.94)	<0.001	
BMI	1.00	1.56 (1.15, 2.10)	1.69 (1.14, 2.50)	1.88 (1.27, 2.76)	0.005	
Waist circumference	1.00	1.62 (1.10, 2.37)	2.95 (2.01, 4.33)	4.96 (3.16, 7.79)	<0.001	
TBF	1.00	1.21 (0.91, 1.62)	1.27 (0.91, 1.78)	1.12 (0.77, 1.63)	0.618	
Waist circumference	1.00	1.78 (1.22, 2.60)	3.40 (2.40, 4.82)	5.81 (3.92, 8.60)	<0.001	
%BF	1.00	1.12 (0.79, 1.58)	1.10 (0.79, 1.54)	0.91 (0.68, 1.21)	0.366	
Waist circumference	1.00	1.68 (1.16, 2.44)	3.10 (2.03, 4.75)	5.16 (3.19, 8.33)	<0.001	
Skinfold	1.00	1.23 (0.86, 1.76)	1.21 (0.83, 1.77)	1.09 (0.70, 1.68)	0.953	

CRP, C-reactive protein; HDL, high-density lipoprotein; TBF, total body fat; %BF, percentage body fat.

* Multivariable adjusted for age, race/ethnicity, a high school education, alcohol consumption, physical inactivity, current and former smoking, and one other measure of adiposity.

† Each model has two measures of adiposity (e.g., waist circumference and TBF) included in the model.

‡ Systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg and/or use of anti-hypertensive medication.

§ Fasting glucose ≥126 mg/dL or non-fasting glucose ≥200 mg/dL and/or use of anti-diabetes medication.

¶ Serum CRP ≥1.0 mg/dL.

** HDL-cholesterol <40 mg/dL for men or <50 or mg/dL for women.

Table 4. Multivariable adjusted* odds ratios (95% confidence interval) of hypertension, diabetes, elevated CRP, and low HDL-cholesterol associated with quartiles of two measures of adiposity† among women

	Quartile 1	Quartile 2	Quartile 3	Quartile 4	*p* value for linear trend	*p* value for curvilinear trend
Hypertension‡						
Waist circumference	1.00	1.26 (0.86, 1.85)	2.39 (1.44, 3.97)	4.41 (2.59, 7.54)	<0.001	
BMI	1.00	0.81 (0.60, 1.10)	0.99 (0.70, 1.40)	1.18 (0.77, 1.80)	0.209	
Waist circumference	1.00	1.16 (0.79, 1.70)	2.34 (1.47, 3.73)	4.46 (2.50, 7.94)	<0.001	0.039
TBF	1.00	1.14 (0.81, 1.60)	0.95 (0.61, 1.49)	1.29 (0.74, 2.25)	0.422	
Waist circumference	1.00	1.04 (0.70, 1.55)	1.85 (1.15, 2.98)	3.68 (2.12, 6.39)	<0.001	0.003
%BF	1.00	1.48 (1.01, 2.16)	1.50 (0.98, 2.28)	1.69 (0.99, 2.89)	0.099	
Waist circumference	1.00	1.30 (0.90, 1.87)	2.87 (1.86, 4.42)	6.38 (4.14, 9.83)	<0.001	0.035
Skinfold	1.00	0.91 (0.65, 1.27)	0.70 (0.48, 1.01)	0.78 (0.53, 1.15)	0.174	
Diabetes§						
Waist circumference	1.00	2.42 (0.56, 10.5)	4.67 (1.18, 18.5)	14.0 (3.57, 54.7)	<0.001	
BMI	1.00	0.71 (0.30, 1.69)	0.59 (0.23, 1.52)	0.82 (0.32, 2.13)	0.620	
Waist circumference	1.00	3.18 (0.71, 14.3)	10.0 (2.16, 46.4)	42.4 (9.29, 193.4)	<0.001	
TBF	1.00	0.39 (0.17, 0.86)	0.20 (0.09, 0.47)	0.24 (0.11, 0.55)	0.013	
Waist circumference	1.00	2.69 (0.64, 11.4)	6.75 (1.50, 30.4)	34.4 (7.74, 152.5)	<0.001	
%BF	1.00	0.64 (0.25, 1.59)	0.37 (0.15, 0.90)	0.24 (0.09, 0.64)	<0.001	
Waist circumference	1.00	2.42 (0.55, 10.8)	4.60 (1.06, 19.9)	16.7 (3.90, 71.7)	<0.001	
Skinfold	1.00	0.56 (0.29, 1.08)	0.63 (0.31, 1.28)	0.58 (0.27, 1.24)	0.326	
Elevated CRP¶						
Waist circumference	1.00	1.29 (0.70, 2.38)	1.32 (0.68, 2.55)	2.82 (1.28, 6.18)	0.003	0.040
BMI	1.00	1.20 (0.75, 1.93)	1.25 (0.73, 2.13)	2.52 (1.31, 4.83)	0.001	0.010
Waist circumference	1.00	1.36 (0.78, 2.38)	1.44 (0.78, 2.66)	3.39 (1.66, 6.92)	<0.001	0.041
TBF	1.00	1.02 (0.61, 1.68)	1.19 (0.75, 1.87)	1.95 (1.06, 3.57)	0.011	
Waist circumference	1.00	1.30 (0.73, 2.33)	1.26 (0.69, 2.31)	3.07 (1.53, 6.17)	<0.001	0.005
%BF	1.00	1.01 (0.62, 1.65)	1.41 (0.89, 2.24)	2.30 (1.32, 4.03)	<0.001	
Waist circumference	1.00	1.35 (0.71, 2.54)	1.39 (0.73, 2.63)	3.47 (1.72, 6.98)	<0.001	0.010
Skinfold	1.00	0.96 (0.61, 1.49)	1.14 (0.67, 1.93)	1.95 (1.10, 3.46)	0.003	0.022
Low HDL-cholesterol**						
Waist circumference	1.00	1.96 (1.45, 2.64)	3.35 (2.36, 4.76)	5.39 (3.57, 8.15)	<0.001	
BMI	1.00	0.83 (0.60, 1.16)	1.07 (0.72, 1.59)	1.18 (0.74, 1.90)	0.314	
Waist circumference	1.00	1.92 (1.39, 2.66)	3.36 (2.30, 4.90)	5.45 (3.69, 8.05)	<0.001	
TBF	1.00	0.93 (0.71, 1.23)	1.04 (0.72, 1.49)	1.21 (0.81, 1.81)	0.321	
Waist circumference	1.00	1.81 (1.33, 2.46)	3.18 (2.22, 4.56)	5.74 (3.97, 8.29)	<0.001	
%BF	1.00	1.07 (0.79, 1.43)	1.20 (0.85, 1.71)	1.15 (0.77, 1.70)	0.443	
Waist circumference	1.00	1.80 (1.36, 2.37)	3.15 (2.36, 4.21)	5.44 (4.15, 7.15)	<0.001	
Skinfold	1.00	1.09 (0.85, 1.39)	1.17 (0.87, 1.58)	1.26 (0.87, 1.82)	0.225	

CRP, C-reactive protein; HDL, high-density lipoprotein; TBF, total body fat; %BF, percentage body fat.

* Multivariable adjusted for age, race/ethnicity, a high school education, alcohol consumption, physical inactivity, current and former smoking, and one other measure of adiposity.

† Each model has two measures of adiposity (e.g., waist circumference and TBF) included in the model.

‡ Systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg and/or use of anti-hypertensive medication.

§ Fasting glucose ≥126 mg/dL or non-fasting glucose ≥200 mg/dL and/or use of anti-diabetes medication.

¶ Serum CRP ≥1.0 mg/dL.

** HDL-cholesterol <40 mg/dL for men or <50 or mg/dL for women.

Table 5. Multivariable adjusted* logistic regression models with two measures of adiposity† as standardized continuous variables with units of 1 standard deviation associated with hypertension, diabetes, elevated CRP, and low HDL-cholesterol

	Hypertension‡	Diabetes§	Elevated CRP¶	Low HDL-cholesterol**
Men (n = 6197)				
Waist circumference (12.6 cm)	1.88 (1.43, 2.48)†	1.51 (0.87, 2.59)	1.41 (0.83, 2.39)	1.85 (1.48, 2.32)††
BMI (4.4 kg/m^2)	0.99 (0.76, 1.29)	1.23 (0.76, 1.99)	0.98 (0.60, 1.62)	1.00 (0.80, 1.24)
Waist circumference (12.6 cm)	1.82 (1.42, 2.35)††	2.43 (1.61, 3.68)††	1.25 (0.79, 1.98)	2.39 (1.99, 2.87)††
TBF (7.8 kg)	1.03 (0.80, 1.32)	0.78 (0.56, 1.08)	1.11 (0.75, 1.63)	0.76 (0.66, 0.89)
Waist circumference (12.6 cm)	1.73 (1.49, 2.00)††	2.08 (1.68, 2.57)††	1.11 (0.82, 1.51)	1.95 (1.66, 2.28)††
%BF (6.0%)	1.12 (0.95, 1.33)	0.85 (0.69, 1.05)	1.39 (1.04, 1.86)	0.93 (0.84, 1.04)
Waist circumference (12.6 cm)	2.22 (1.85, 2.67)††	2.20 (1.73, 2.79)††	1.19 (0.84, 1.67)	2.06 (1.70, 2.51)††
Skinfold thickness (27.6 mm)	0.82 (0.67, 1.01)	0.83 (0.66, 1.03)	1.20 (0.88, 1.63)	0.88 (0.76, 1.03)
Women (n = 6411)				
Waist circumference (14.6 cm)	2.28 (1.74, 300)††	2.72 (1.85, 4.00)††	1.62 (1.30, 2.02)	1.90 (1.47, 2.47)††
BMI (6.0 kg/m^2)	0.91 (0.69, 1.19)	0.82 (0.55, 1.23)	1.27 (1.05, 1.55)	1.07 (0.83, 1.38)
Waist circumference (14.6 cm)	2.30 (1.83, 2.90)††	4.42 (2.91, 6.71)††	1.56 (1.21, 2.02)	2.02 (1.60, 2.54)††
TBF (10.9 kg)	0.90 (0.72, 1.13)	0.49 (0.32, 0.76)	1.32 (1.07, 1.64)	1.01 (0.80, 1.26)
Waist circumference (14.6 cm)	2.12 (1.77, 2.55)††	3.25 (2.38, 4.44)††	1.54 (1.22, 1.95)	2.11 (1.80, 2.48)††
%BF (7.4%)	0.97 (0.84, 1.13)	0.58 (0.41, 0.83)	1.48 (1.12, 1.97)	0.95 (0.81, 1.12)
Waist circumference (14.6 cm)	2.45 (2.00, 3.00)††	2.50 (1.96, 3.20)††	1.60 (1.32, 1.94)	1.93 (1.64, 2.26)††
Skinfold thickness (37.1 mm)	0.81 (0.68, 0.96)	0.86 (0.64, 1.15)	1.38 (1.11, 1.71)	1.06 (0.88, 1.29)

CRP, C-reactive protein; HDL, high-density lipoprotein; TBF, total body fat; %BF, percentage body fat. Data are odds ratios (95% confidence intervals).

* Multivariable adjusted for age, race/ethnicity, high school education, alcohol consumption, physical inactivity, and current and former smoking.

† Each model had two measures of adiposity (e.g., waist circumference and TBF) included in the model.

‡ Systolic blood pressure ≥140 mm Hg and/or diastolic blood pressure ≥90 mm Hg and/or use of anti-hypertensive medication.

§ Fasting glucose ≥126 mg/dL or non-fasting glucose ≥200 mg/dL and/or use of anti-diabetes medication and self-reported doctor diagnosis of diabetes.

¶ Serum CRP ≥1.0 mg/dL.

** HDL-cholesterol <40 mg/dL for men or <50 or mg/dL for women and/or use of cholesterol-lowering medication.

†† $p < 0.001$ for difference between two measures of adiposity.

erides, insulin, and blood pressure after adjustment for waist-to-hip ratio (14). Meanwhile, waist-to-hip ratio was not associated with any of the risk factors after adjustment for TBF.

Because hydrostatic weighing is impractical to use in large epidemiological studies, BIA is considered the most valid and reliable method to assess TBF and %BF (23–25). Despite being validated in a population composed primarily of white participants with a limited number of black participants, Sun et al. (26) described the prediction equations as having overall excellent performance in whites and blacks. However, other ethnic groups were not included in the validation of these equations. BIA has been found to be a reliable method for assessing TBF and %BF when a protocol is followed that controls for factors that may affect the measurement (25–28). Notable exceptions include the assessment of individuals with medical conditions resulting in major disturbances in water distribution, such as amputations, and individuals at extreme weight ranges. We repeated all analyses excluding NHANES participants with a BMI ≥40 kg/m^2 (n = 282), and the results were remarkably similar, indicating our findings are robust and not influenced by differential BIA measurements among very obese individuals (data not shown).

In this study, the OR of diabetes associated with higher TBF and %BF was decreased after adjustment for waist circumference among women. Given the direct association of TBF and %BF with diabetes observed in Table 2 and the extremely large OR of diabetes associated with waist circumference, this finding may be the result of overcompen-

Table 6. Multivariable adjusted* logistic regression models with two standardized measures of adiposity† as standardized continuous variables with units of 1 standard deviation associated with elevated HOMA-IR, elevated triglycerides, and high LDL-cholesterol

	HOMA-IR ≥3.0	Triglycerides ≥150	High LDL-cholesterol‡
Men (n = 2690)			
Waist circumference (12.6 cm)	2.82 (1.95, 4.08)§	1.77 (1.14, 2.73)	1.21 (0.86, 1.69)
BMI (4.4 kg/m^2)	1.56 (1.11, 2.20)	1.12 (0.75, 1.69)	1.00 (0.70, 1.44)
Waist circumference (12.6 cm)	3.65 (2.53, 5.27)§	2.02 (1.31, 3.10)§	1.32 (0.97, 1.79)§
TBF (7.8 kg)	1.21 (0.86, 1.71)	0.98 (0.66, 1.46)	0.92 (0.70, 1.20)
Waist circumference (12.6 cm)	3.94 (3.04, 5.11)§	1.76 (1.38, 2.24)§	1.11 (0.91, 1.36)
%BF (6.0%)	1.19 (0.95, 1.50)	1.19 (0.93, 1.53)	1.14 (0.94, 1.38)
Waist circumference (12.6 cm)	4.35 (3.16, 5.97)§	2.15 (1.71, 2.68)§	1.23 (0.94, 1.62)
Skinfold thickness (27.6 mm)	1.01 (0.79, 1.31)	0.91 (0.72, 1.14)	0.98 (0.76, 1.27)
Women (n = 2860)			
Waist circumference (14.6 cm)	2.74 (2.00, 3.74)	2.93 (2.17, 3.97)§	1.38 (1.10, 1.73)
BMI (6.0 kg/m^2)	1.96 (1.37, 2.81)	0.79 (0.60, 1.03)	1.16 (0.94, 1.45)
Waist circumference (14.6 cm)	4.21 (3.04, 5.83)§	3.13 (2.12, 4.60)§	1.62 (1.22, 2.17)§
TBF (10.9 kg)	1.23 (0.86, 1.76)	0.74 (0.53, 1.03)	0.97 (0.76, 1.23)
Waist circumference (14.6 cm)	4.24 (3.28, 5.50)§	1.94 (1.47, 2.56)§	1.22 (0.95, 1.56)
%BF (7.4%)	1.29 (0.96, 1.73)	1.27 (0.98, 1.66)	1.36 (1.12, 1.64)
Waist circumference (14.6 cm)	3.58 (2.57, 4.99)§	2.09 (1.66, 2.64)§	1.36 (1.10, 1.69)
Skinfold thickness (37.1 mm)	1.61 (1.18, 2.19)	1.16 (0.91, 1.47)	1.19 (0.96, 1.48)

HOMA-IR, homeostasis model analysis insulin resistance; LDL, low-density lipoprotein; TBF, total body fat; %BF, percentage body fat. Data are odds ratios (95% confidence intervals).

* Multivariable adjusted for age, race/ethnicity, high school education, alcohol consumption, physical inactivity, and current and former smoking.

† Each model had two measures of adiposity (e.g., waist circumference and TBF) included in the model.

‡ LDL-cholesterol ≥130 mg/dL and/or use of cholesterol-lowering medication.

§ $p < 0.05$ for difference between two measures of adiposity.

sation. While measuring BIA may be important in some settings, this study indicates waist circumference maintains a stronger association with cardiovascular disease risk factors and, therefore, may be more valuable in most health care and research settings.

Some participants' skinfold measurements were larger than could be measured with the calipers used in NHANES III, and we considered those values to be 1 mm larger than the largest respective skinfold measurement. Results were nearly identical when skinfold measurements too large for the calipers were set to 1 standard deviation higher than the largest respective skinfold measurement. Additionally, the analysis was repeated to determine the association between triceps, subscapular, suprailiac, and thigh skinfolds separately and cardiovascular disease risk factors after adjustment for waist circumference, producing similar results.

Among the measures studied, waist circumference, a measure of visceral fat, was the only one that considered the regional distribution of adipose tissue on the body (29). Although computed tomography is considered the gold standard for measuring visceral fat, it is often too costly and burdensome for use in large epidemiological studies and routine clinical practice. Anthropometric measurements, such as waist circumference, are currently the most reliable and feasible method of measuring visceral fat in large epidemiological studies and for routine clinical practice.

It has been suggested that visceral fat increases cardiovascular disease risk more so than subcutaneous fat because of differences in vascular anatomy and metabolic activity. Unlike subcutaneous fat, visceral fat is drained by the portal venous system and has a direct connection with the liver, resulting in an influx of free fatty acid availability in the liver. In visceral fat, mobilization of free fatty acids is faster because of higher lipolytic activity in visceral adipocytes, resulting in higher free fatty acids in the systemic circulation. Additionally, an influx of free fatty acid availability in the liver decreases hepatic insulin extraction, resulting in systemic hyperinsulinemia, and inhibits the suppression of glucose production by insulin. Furthermore, the influx of free fatty acid availability leads to increased secretion of very LDL-cholesterol. The resulting increase in hepatic lipase activity results in the removal of lipids from LDL- and HDL-cholesterol particles making them smaller and denser, and decreased HDL-cholesterol levels (29,30).

In this study, waist circumference was measured at the iliac crest. This is different than other large population-based studies, such as the Framingham Heart Study and the Atherosclerosis Risk in Communities Study, which measured waist circumference at the umbilicus (31,32). Various waist circumference measurement sites have been found to differ slightly in magnitude. Although all waist circumference measures, regardless of site, are strongly associated with visceral fat, the correlations with visceral fat at different sites may differ in magnitude (33,34).

A major limitation of this study is the cross-sectional nature of NHANES III. Therefore, caution should be taken when making conclusions regarding the relative importance of each measure of adiposity in the development of cardiovascular disease risk factors and coronary heart disease incidence. An additional limitation in the continuous analysis is that the ORs for associations with a significant curvilinear trend may be attenuated at one end and stronger at the other end of the range of adiposity.

In a large nationally representative sample of U.S. adults, waist circumference was a better predictor of cardiovascular disease risk factors than BMI, TBF, %BF, or skinfold thickness. The results of this analysis were consistent for multiple cardiovascular disease risk factors and in several sets of analyses. Therefore, strong consideration should be given toward using waist circumference to assess an individual's risk for cardiovascular disease, especially considering the ease of measurement and low cost. Based on these data, waist circumference may provide the greatest value in health care settings for assessing cardiovascular disease risk.

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