

Development and comparison of two field-based body fat prediction equations: NHANES 1999 - 2004

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ABSTRACT

International Journal of Exercise Science 5(3): 223-231, 2012. Clinical guidelines define obesity in terms of excess body weight adjusted for height (i.e., body mass index [BMI] categories) and/or gender-specific waist circumference (WC) cut-point values. Since body composition, particularly fat mass, is the most variable among individuals due to differences by gender, age, and race, and total percent body fat (%BF) can be estimated accurately using dual-energy X-ray absorptiometry (DXA), the purpose of this study was to develop and compare two field-based body fat prediction equations suitable for a nationally representative sample of the US adult population. Data were analyzed from subjects 20+ years of age (n = 11,907) with BMI and WC values, and that participated in DXA scans as part of the 1999-2004 National Health and Nutrition Examination Survey (NHANES). Multiple linear regression was used to develop and compare DXA-estimated %BF as the dependent variable versus BMI or WC, gender, age, and race as predictor variables. Mean values for age, BMI, WC, and %BF among the sample were 46.84 ± 0.30 years, 28.17 ± 0.11 kg/m², 96.69 ± 0.27 cm, and 34.19 ± 0.14 %, respectively. Both equations were similar in terms of explained variance, with R² values of 0.82 for the BMI and WC equations, respectively. Both equations are easy to use, and could easily be developed as an application on a smartphone or other handheld device, or simply integrated into a spreadsheet for use as an additional tool for health professionals to assess the current health status of individuals based on predicted body fat from BMI, WC, and demographics.

KEY WORDS: Obesity, adults, BMI, waist circumference, gender, race, DXA

INTRODUCTION

Obesity is a significant public health problem in the US and worldwide (5). Clinical guidelines define obesity in terms of excess body weight adjusted for height (i.e., body mass index [BMI]) 25 (21). Therefore, overweight in adults is defined as a BMI between 25.0 kg/m² and 29.9 kg/m², and adults are considered obese if their BMI is at or above 30 kg/m²,

regardless of gender, age, or race-ethnicity (21). Obesity is associated with increased risk of multiple chronic diseases, and elevated abdominal obesity, assessed by measuring waist circumference (WC), is also associated with increased chronic disease risk. Clinical guidelines for excess WC are gender-specific and have been set at 102 cm for men and 88 cm for women (21). Despite a high correlation between both BMI and WC with total percent body

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fat (%BF) estimated from dual-energy X-ray absorptiometry (DXA) (7), field-based body fat prediction equations can be particularly useful for health professionals given that BMI and WC are merely proxies for excess body fat, which varies considerably by age, gender, and race-ethnicity (2, 3, 4, 35 9, 10, 12). Therefore, the purpose of this study was to develop and compare two body fat prediction equations based on BMI or WC, gender, age, and race-ethnicity, using multiply imputed DXA data obtained from participants 20+ years of age that participated in the 1999- 2004 National Health and Nutrition Examination Survey (NHANES).

METHODS

Data Source

The NHANES is a continuous data collection initiative conducted by the National Center for Health Statistics (NCHS) of the Centers for Disease Control and Prevention (CDC) (17). The NHANES design is a stratified, multistage probability sample based on counties, blocks, 11 households, and the number of people within households. Data are collected via household interviews and health examinations at a mobile examination center (MEC). Detailed information regarding the NHANES survey design, procedures, and protocols can be found online (17). Due to the nature of the analysis (secondary data analysis), and the lack of personal identifiers, this study was deemed exempt by the Louisiana State University Agricultural Center Institutional Review Board.

Body composition assessment

Beginning in 1999, NHANES began collecting whole-body DXA scans on survey subjects 8 years of age and older to provide nationally representative data on body composition. These data were collected across three survey cycles (1999-2000, 2001-2002, and 2003-2004) and were subsequently released as public-use data files in 2008 (16). The 1999-2004 NHANES DXA data sets contain estimates of absolute and relative total and regional body composition including fat mass, bone-free lean-tissue mass, and bone mineral. Trained technicians obtained whole-body DXA scans in a MEC using a Hologic QDR 4500A fan-beam densitometer (Hologic, Inc., Bedford, MA). Details regarding DXA procedures are described in the NHANES documentation (16). Briefly, participants were positioned supine on the tabletop with their feet in a neutral position and hands flat by their side. A Velcro strap was used to keep the feet stationary and together. All scans were reviewed and analyzed (using Hologic software version 8.26:a3) by the NHANES quality control center at the University of California, San Francisco, Department of Radiology. Further details of the DXA examination protocol are documented in the NHANES Body Composition Procedures Manual (14, 15). Of the 21,230 examined participants age 8 years of age and older who were eligible for the DXA scan, 19,040 completed DXA scans, and valid total body measurements (all regions 12 were able to be analyzed accurately) were obtained from 16,973 or 80% of examined participants (1). Beyond planned exclusions (i.e., pregnant females), a number of participants were missing valid DXA data. The percentage of participants with valid data decreased with increasing age, primarily because of

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implants (i.e., pacemakers, stents, hip replacements) and other artifacts such as metal which can affect the accuracy of the DXA results. Additionally, the DXA scanner cannot penetrate much thicker than 15 cm, after which the accuracy of segmenting bone is limited. Similarly, height (6'5") and weight (300 lbs.) limits of the DXA machine precluded certain subjects from being eligible to participate.

Because data were not missing completely at random, and therefore could not be treated as a random subset of the population, missing DXA values were imputed in the public-use data sets. Multiple imputation was carried out by the NCHS to allow analyses to reflect additional variability due to the use of imputed values for the missing data (16, 20). With multiple imputation, M (in this case, M = 5) versions of the imputed values are created randomly and independently, resulting in M completed data sets. Each data set is analyzed separately and the M sets of results are combined, with the variability across the M analyses measuring the additional variability due to missing data. Details regarding the multiple imputation procedures are described elsewhere (16, 20). Briefly, a sequential regression multivariate imputation procedure (19) was implemented separately within 10 age-by-gender groups. A large number of predictors were used, including non-DXA variables analyzed.

Statistical Analysis

All analyses were conducted using SAS version 9.2 (SAS Institute, Cary, NC) and SAS89 callable SUDAAN version 10.0.1 (RTI, Research Triangle Park, NC) to adjust the variance for the complex survey design

of NHANES. Age-adjusted, sample-weighted means and standard 13 errors of the variables were calculated using PROC DESCRIPT. T-tests with Bonferroni adjustments for multiple comparisons were used to assess the significance of differences between point estimates. The Bonferroni adjustment is a statistical adjustment for significance across the entire analysis, performed by dividing the nominal p value of 0.05 for a single test by the number of comparisons performed. Global differences for categorical variables were tested using χ^2 tests, and Wald F tests were used to test for differences among means of continuous variables. Mean (\pm SE) unadjusted body composition, and t test statistics for differences between means were calculated for continuous variables using PROC DESCRIPT of SUDAAN. The standard errors of the means were estimated by Taylor Series Linearization (11), a method that incorporates the sample weights and accounts for the complex sample design of NHANES. For the 6-years 1999-2004, a 6-year MEC weight variable was created by assigning 2/3 of the 4-year weight for 1999-2002 if the person was sampled in 1999-2002 or assigning 1/3 of the 2-year weight for 2003-2004 if the person was sampled in 2003-2004. Six-year MEC weights were applied to the data to account for differential probabilities of selection, nonresponse, and non-convergence, as recommended.

Regression analysis

Multiple linear regression analyses were used to describe the strength of association of DXA-measured percent fat as the dependent variable with BMI or WC, age, gender, and race ethnicity as predictor variables. Gender was included as a

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dichotomous variable (i.e., 0 for women, 1 for men) and race-ethnicity was coded from 1 to 3 with non-Hispanic whites as the reference to account for differences in %BF by gender and race-ethnicity. The SUBPOPN statement of SUDAAN was used to restrict the analysis to adults 20+ years of age, and to three race-ethnicity groups. Non-Hispanic white women were treated as the reference group. Age in 14 years was calculated at the time of the interview and race-ethnicity was self-reported. For the purposes of this study, race-ethnicity was restricted to the following three major US ethnic groups: Non-Hispanic Whites (NHW), Non-Hispanic Blacks (NHB), and Mexican Americans (MA). Height and weight were measured using a Seca electronic stadiometer and a Toledo electronic weight scale, respectively, using standardized techniques and equipment (14, 15). Waist circumference was measured just above the iliac crest (14, 15). The total number of non-pregnant subjects 20+ years of age with non-missing percentbody fat data was 13,091. Of these participants, 1,019 were excluded based on self-reported race ethnicity of Hispanic or Other; and among the remaining 12,072 participants, 165 were missing BMI data. Therefore, the total analytic sample for this study consisted of 11,907 subjects.

RESULTS

The sample consisted of 5,981 men and 5,926 women. Of these, 80% were NH-Whites (NHW), 12% NH-Blacks (NHB), and 8% Mexican Americans (MA). Mean values

and standard errors (SE) for age, BMI, and percent body fat among men and women were: 46.3 ± 0.4 and 46.4 ± 0.5 years; 28.0 ± 0.10 and 28.2 ± 0.16 kg/m²; 28.2 ± 0.09 and 39.8 ± 0.17 %, respectively.

Table 1. Demographic characteristics of the analytic sample of adults 20+ year of age by gender (n=11,907): NHANES 1999-2004.

Variable	Men	Women
Unweighted sample size	5981	5926
Weighted percentage (%)	49.0	51.0
Age at screening (y)	46.3 ± 0.43^1	46.4 ± 0.51
Race-Ethnicity (% of total)		
Non-Hispanic white (NHW)	80.0	80.0
Non-Hispanic black (NHB)	11.1	12.8
Mexican American (MA)	8.9	7.2
Height (cm)	176.5 ± 0.12	162.6 ± 0.11^2
Weight (kg)	87.4 ± 0.30	74.7 ± 0.42^2
BMI (kg/m ²)	28.0 ± 0.10	28.2 ± 0.16
Waist circumference (cm)	99.99 ± 0.24	93.12 ± 0.38^2
Body fat (%)	28.2 ± 0.09	39.8 ± 0.17^2

¹ Mean \pm SE (all such values).

² Significantly different from men, $P < 0.05$.

Table 2 shows comparisons in age and body composition by race-ethnicity and stratified by gender. Compared to NHW and NHB, MA men and women were significantly younger and shorter. Weight was similar between NHW and NHB men, and between NHW and MA women. No differences were observed in BMI among the men. In contrast, NHB women had significantly higher mean BMI values than MA and NHW women, and MA women also had significantly higher mean BMI values than NHW women. Waist circumference was highest among NHW men and NHB women. Finally, percent body fat was lowest among NHB men and NHW women, when compared to the other two groups (Table 2).

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Table 2. Demographic characteristics of subjects¹

Variable	Men			Women		
	NH-White	NH-Black	Mexican American	NH-White	NH-Black	Mexican American
Age (y)	46.8 ± 0.4 ^a	42.6 ± 0.5 ^b	37.4 ± 0.6 ^c	48.9 ± 0.4 ^a	44.5 ± 0.5 ^b	39.5 ± 0.8 ^c
Weight (kg)	88.4 ± 0.4 ^a	87.5 ± 0.7 ^a	80.8 ± 0.7 ^b	73.6 ± 0.5 ^a	83.3 ± 0.6 ^b	72.2 ± 0.7 ^a
Height (cm)	177.4 ± 0.15 ^a	176.9 ± 0.15 ^a	169.9 ± 0.27 ^b	162.9 ± 0.14 ^a	163.0 ± 0.19 ^a	157.6 ± 0.23 ^b
BMI (kg/m ²)	28.1 ± 0.1	27.9 ± 0.2	27.9 ± 0.2	27.7 ± 0.2 ^a	31.3 ± 0.2 ^b	29.1 ± 0.3 ^c
WC (cm)	100.9 ± 0.3 ^a	95.7 ± 0.5 ^b	96.9 ± 0.6 ^b	92.6 ± 0.5 ^a	98.3 ± 0.6 ^b	93.9 ± 0.8 ^a
Body fat (%)	28.5 ± 0.1 ^a	25.5 ± 0.2 ^b	28.1 ± 0.3 ^a	39.8 ± 0.2 ^a	40.6 ± 0.2 ^b	40.9 ± 0.3 ^b

¹ Mean ± SE (all such values).

^{abc} Rows with different superscript alphabetic character are significantly different ($P < 0.05$, Bonferroni-corrected).

Table 3. Multiple linear regression analysis of DXA-measured percent body fat versus body mass index (BMI) or waist circumference (WC), gender, age, and race among adults 20+ years of age (n=11,907): NHANES 1999-2004

Coefficient	BMI				Waist circumference			
	β	SE	Standardized Estimate	R ²	β	SE	Standardized Estimate	R ²
Intercept	13.45	0.39	--	--	6.56	0.43	--	--
BMI, kg/m ²	0.79	0.01	0.57	0.35	--	--	--	--
WC, cm	--	--	--	--	0.34	0.00	0.59	0.20
Gender ¹	-11.47	0.08	-0.65	0.78	-13.99	0.09	-0.79	0.81
Age, y	0.09	0.00	0.17	0.81	0.04	0.00	0.08	0.82
Race ² :								
	(NHB)	-1.98	0.13		-0.98	0.13		
	(MA)	0.71	0.14	-0.01	0.82	1.21	0.14	0.02

β =beta coefficient; SE=standard error. All β 's significant ($P < 0.0001$).

¹Gender: 0=women, 1=men.

²Race: 0=NHW, 1=NHB, 2=MA.

The multiple linear regression results are shown in Table 3. Both equations were similar in terms of total explained variance. The combination of gender, BMI or WC, age, and race-ethnicity explained 82% of the variance in percent body fat. Body mass index explained 35% of the variance in %BF, compared to 20% by waist circumference. However, when gender was included in the models, the R² values increased to 0.81 in the WC equation and 0.78 in the BMI equation. Interestingly, age explained an additional 3% of the variance in %BF when added to the BMI equation, compared to only 1% in the WC equation.

Finally, race contributed minimally to both equations, with negative beta coefficients for non-Hispanic blacks which equates to less %BF compared to the other groups (Table 3).

The formulas for calculating %BF based on BMI and WC are shown below: %BF = (0.8 x BMI) - (11.5 x gender) + (0.1 x age) - (2.0(NHB) [or + 0.7(MA)] x ethnicity) + 13.45 and %BF = (0.3 x WC) - (14.0 x gender) + (0.04 x age) - (1.0(NHB) [or + 1.2(MA)] x ethnicity) + 6.6 Where gender = 0 for women, 1 for men; race-ethnicity = 0 for NHW, 1 for NHB, and 2 for MA.

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A plot of %BF versus BMI (Fig. 1) and waist circumference (Fig. 2) by gender is shown below. As expected, men had lower BMI and waist circumference values across the entire range of body fat percentages. Additionally, the BMI - %BF relationship appeared to be somewhat curvilinear, whereas the WC - %BF relationship appeared to be slightly more linear for both men and women.

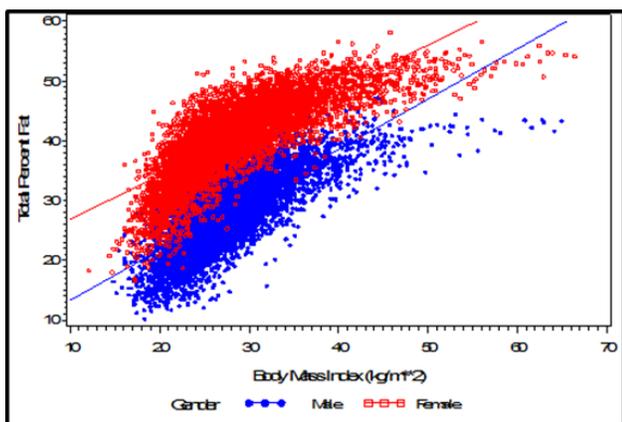


Figure 1. Total percent body fat versus body mass index in men and women.

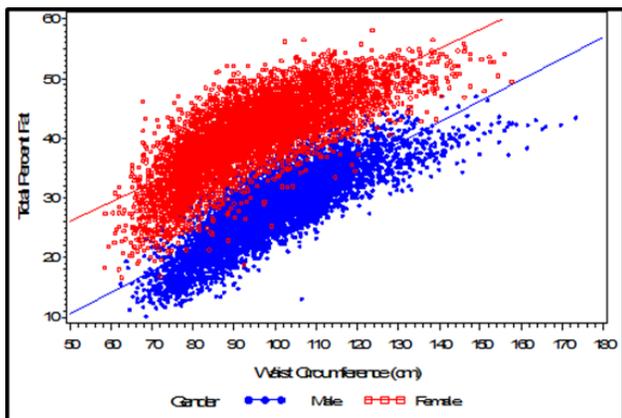


Figure 2. Total percent body fat versus waist circumference in men and women.

DISCUSSION

The aim of this study was to develop and compare two body fat prediction equations appropriate for use with a nationally

representative sample of the US adult population and based on BMI and WC. The primary finding was that both equations predicted percent body fat with approximately the same group accuracy. The NHANES data indicate that the combination of BMI or WC, along with age, gender, and race-ethnicity significantly improve the prediction of DXA-measured percent fat. Given the widespread use of BMI and WC as proxies for obesity, future studies should consider including underrepresented minority groups with BMI or WC when developing body fat equations in other populations.

Body mass index and WC are simple, easy-to-use methods of estimating obesity in population-based studies. Several other studies have developed generalized body fat prediction equations for adults based on BMI, and a meta-analysis has been done (4). Gallagher et al. (8) reported an R^2 of 0.67 and a SEE of 5.68% when combining BMI with age and gender. In that study which included 504 White and 202 Black males and females aged 20-94, race-ethnicity did not significantly influence the %BF - BMI relationship. Furthermore, significant differences were noted in weight, BMI, fat mass, percent fat, and fat-free mass between White and Black females. However, only waist circumference was different between the males. These findings are similar to those obtained from this study, with several differences noted in females but not males. While the use of BMI has shown to be a reasonable measure of adiposity in adults, some research suggests that BMI may be a poor indicator of body fatness in certain population subgroups, such as ethnic minorities (2), and individuals with a large body build (3).

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Men generally have less body fat than women, and NH-Blacks typically have higher bone mineral density than other ethnic groups (1-4, 8, 9, 12, 13). Using the same data set reported on in this study, Flegal and colleagues observed correlations between BMI and %BF ranging from 0.72 among males and females 80+ years of age, to 0.84 in young adult females 20-39 years (7). Similar patterns were noted for WC and %BF, with correlations ranging from 0.65 in females 80+ years of age, to 0.86 in young adult males 20-39 years (7). The NHANES DXA data have been reported by several others to compare DXA measured %BF to BMI and other anthropometric measures in children (6) and adults (7); to describe differences in whole body and regional bone mineral density (13); and to develop a body composition reference database including an obesity classification scheme based on fat mass divided by height squared (10). Finally, these data have been examined by the NHANES study group and released on the CDC website to fully describe population estimates of fat, lean, and bone among the US population by age, gender, and race-ethnic group (1). Unique to this study was the use of the NHANES DXA data set to provide field-based prediction equations to estimate percent body fat. Equipped with measurements of height, weight, and WC which are easily obtained in the field, combined with age, gender, and race¹⁹⁵ ethnicity, health professionals in a variety of settings can utilize these results to predict percent body fat. Although other studies have developed prediction equations using more complex models (*i.e.*, four-component [4-C] models) based on anthropometric measures (18, 22), the results observed from this study in terms of model prediction are comparable

to previous findings, in the sense that the prediction equations explained 82% of the variance in %BF from DXA. The utility of these results are further strengthened by the use of a nationally representative sample of US adults. From a practical standpoint, the prediction models developed are parsimonious, while maintaining a high level of accuracy and precision. The limitations of this study include its cross-sectional design to derive models to predict percent fat. Such a design limits conclusions about causal inference and generalizability. Furthermore, because the NHANES 1999-2004 datasets were designed to oversample Mexican Americans and non-Hispanic blacks, the results cannot be generalized to individuals of other race-ethnic groups such as Asians or Hispanics. Additional studies are needed to cross-validate the equations developed to assess intra-individual accuracy within the group.

In conclusion, this study found that BMI and WC predicted %BF equally well among a representative sample of the US population. This study provides an additional tool for health professionals to use to assess individual health status based on excess body fat rather than excess weight adjusted for height or waist circumference alone. Both equations developed are easy to use, and could be developed as an application on a smartphone or other handheld device, or simply integrated into a spreadsheet for use as an additional tool for health professionals to assess the current health status of individuals based on predicted body fat from BMI, WC, and demographics.

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