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Ethnic Bias in Anthropometric Estimates of DXA Abdominal Fat: the TIGER Study

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Abstract

Background/Introduction—The purpose of this study was to examine race/ethnicity bias of using waist circumference (WC) to estimate abdominal fat.

Methods—A total of 771 females and 484 males (17–35 y) were tested one to three times during a prescribed 30-week aerobic exercise program. The race/ethnicity distribution for women was: non-Hispanic white (NHW), 29%; Hispanic, 25%; African-American (AA), 35%; Asian-Indian, 3%; and Asian, 8%. The distribution for men was: NHW, 37%; Hispanic, 26%; AA 22%; Asian-Indian, 5%; and Asian, 10%. Abdominal fat (L1 to L5) was estimated from whole body scanning using dual energy x-ray absorptiometry (DXA Abd-Fat).

Results—DXA Abd-Fat varied by race/ethnicity after accounting for WC and height in both women and men. The increase in DXA Abd-Fat per increase in WC was lower in the Asian and Asian-Indian women than in the other women. The increase in DXA Abd-Fat per increase in WC was higher in the AA men and lower in the Asian-Indian men than in the other men. These differential race/ethnicity effects were most notable when WC exceeded 90 cm in the women and 100 cm in the men, values which are consistent with current definitions of abdominal obesity in the United States.

Conclusions—Prediction equations for abdominal fat using WC that do not account for race/ethnicity group provide biased estimates. These results may affect assessment of disease risk from abdominal obesity among racial/ethnic groups.

Keywords

obesity; visceral fat; body composition; linear models

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Introduction/Background

Paragraph Number 1

The relative distribution of fat and lean mass, particularly deposition of adipose tissue in the abdominal region, has recently been identified as a risk factor for the development of cardiovascular disease and other co-morbid states (3, 6). The laboratory methods used to assess abdominal obesity include computed tomography (CT) and dual-energy x-ray absorptiometry (DXA). CT scanning is considered the “gold standard” due to its ability to identify and quantify subcutaneous and visceral body fat depots separately (6–7). DXA has become the most common laboratory method to measure body composition and has the capacity to measure lean mass, fat mass and bone mineral content of the total body and for body compartments (9).

Paragraph Number 2

Anthropometric methods that have been used to assess abdominal adiposity include waist and hip circumference, waist/hip ratio, and body mass index (BMI) (22). There is growing evidence of a race/ethnicity group bias associated when using anthropometric measures to assess adiposity of adults (3, 5–8, 12–13, 21–22). In the HERITAGE Family Study (22), hip and waist circumferences in combination with BMI provided reasonably accurate estimates of CT-measured abdominal visceral fat (women $r = .85$, men $r = .88$) but the anthropometric model systematically overestimated the abdominal visceral fat of African-American (AA) men and women. What is not understood is the race/ethnicity bias of anthropometric variables when evaluating abdominal fat in research and field settings. This study examined the race/ethnicity bias of anthropometric models to measure DXA abdominal fat (DXA Abd-Fat) of diverse young men and women.

Methods

Paragraph Number 3

Subjects—Subjects were recruited from the TIGER (Training Intervention and Genetics of Exercise Response) study (20). The TIGER subjects were students enrolled at the University of Houston, Houston, TX. The target subject was a sedentary person under the age of 35 y who exercised less than 30 min per week for the previous 30 days, and was not actively limiting caloric intake by dietary modification. Subjects were excluded from the study if they had a physical or physiological contraindication to aerobic exercise, a known metabolic disorder that may alter body composition, or were pregnant or lactating. The study was approved by the University of Houston Committee for the Protection of Human Subjects, and all subjects volunteered to participate by signing informed consent.

Paragraph Number 4

The TIGER study subjects engaged in 30 weeks (2 semesters, or 9 calendar months) of exercise training, three days per week for 30-min per day at 65–85% of age- and gender-specific predicted heart rate reserve (19). The data came from five yearly cohorts. The sample consisted of 771 women and 484 men who ranged in age from 18 to 35 y. These data included men and women who had from one to three measurement visits over the 9-month exercise training program. The measurements were obtained at baseline (enrollment), at 15 weeks, and at 30 weeks.

Paragraph Number 5

The total number of measurements was 1,293 for women and 824 for men. The racial/ethnic group composition of the male and female samples differed slightly. The composition of the

men was: non-Hispanic white or Caucasian (NHW), 37%; Hispanic, 25%; African-American (AA), 22%; Asian-Indian, 5%; and Asian, 9%. The composition of the women was: NHW, 29%; Hispanic, 24%; AA, 35%; Asian-Indian, 4%; and Asian, 8%. Tables 1 and 2 provide subject characteristics at the baseline measurement stratified by sex and race/ethnicity group.

Paragraph Number 6

Measurements—Height was measured with a stadiometer (Seca Road Rod, Hanover, MD) and body weight was measured using a digital scale (Seca 770, Hanover, MD). Waist circumference (WC) was measured by the same investigator at each time point using a Gulick tension-calibrated tape measure (Creative Health Products, Ann Arbor, MI) and standard technique. BMI was calculated using the standard Quetelet index equation [$BMI = \text{weight(kg)} / \text{height(m)}^2$]. Prior to DXA scanning, all women completed a standard urine pregnancy test. Subjects were asked to lie in a supine position and whole body scans were collected using a Hologic Discovery-W (Bedford, MA). Post acquisition analysis was completed using the adult whole body software module (QDR v.12.3). A “region of interest” (ROI) box was added to delineate the abdominal compartment (L1-L5).

Paragraph Number 7

Statistical Methods—A random intercept model fitted using maximum likelihood, linear mixed models regression (LMM) with the Stata 11 (Statacorp, College Station, TX) xtmixed program was used for data analysis (18, 23). The dependent variable was abdominal fat, defined as the body fat component of the DXA abdominal ROI. The fixed effects included in all models were WC, height, and race/ethnic group. The NHW group was the referent. All models included a random intercept term to account for the within-subjects dependency due to repeated tests (18).

Paragraph Number 8

Anthropometric model 1 included WC and height, with measurement period as a control variable and model 2 (full model) added race/ethnicity group and race/ethnicity group by WC interaction terms to the initial model. Both WC and the WC-race/ethnicity interaction terms were centered using the WC grand mean to reduce collinearity effects. Each fixed effect coefficient was tested with a Wald z statistic to eliminate variables that were not significantly different from zero (23, 26). Likelihood ratio tests (18, 23) were used to compare initial and final model fit. Model fit was also assessed at each stage of the analysis; model residuals and random intercepts (empirical Bayes’ best linear unbiased predicted values) were graphically examined with histograms and normal probability plots and were plotted against the respective fixed-effects predicted scores (18, 23). Because of the well-documented sex differences in body fatness, the women and men’s data were analyzed using separate models.

Paragraph Number 9

The DXA Abd-Fat distributions of both men and women were positively skewed and had curvilinear relations with most of the other study variables, so DXA Abd-Fat was log-transformed [$\ln(\text{Abd-Fat})$] to approximate normality and linear associations. The dependent variable for these analyses was $\ln(\text{Abd-Fat})$. Consequently, for the continuous variables the regression coefficients, β , represented the proportional unit difference in DXA Abd-Fat per unit difference in the respective independent variable; the equation $100(e^{\beta} - 1)$ was used to compute the proportional change (4). For categorical variables, such as race/ethnicity, the regression coefficients represented proportional differences in DXA Abd-Fat of the

respective race/ethnic group relative to the NHW reference group after adjusting for other variables in the model.

Tables 1 and 2 provide the descriptive statistics for the men and women. Provided are the means and standard deviations for the total samples and contrasted by race/ethnic group.

Results

Paragraph Number 10

Tables 1 and 2 provide the descriptive statistics for the men and women. Provided are the means and standard deviations for the total samples and contrasted by race/ethnic group. Tables 3 and 4 provide the LMM results. For the women, Model 1 included WC, WC squared (WC^2), and height, all of which were significantly related to $\ln_{(Abd-Fat)}$. Adding race/ethnicity and the interaction of race/ethnicity to Model 1 to form Model 2 significantly improved model fit ($p < 0.001$). After statistically adjusting for the effects of height, DXA Abd-Fat was proportionately higher for a given WC in the Hispanic (9.0%, $p = 0.001$) and Asian-Indian (24.5%, $p < 0.001$) women and lower in the AA women (-7.5% , $p = 0.001$) compared to the NHW women (Table 3). Furthermore, for every 1-cm increase in WC, DXA Abd-Fat increased at a 0.70% lower rate in the Asian-Indian ($p = 0.029$) women and a 1.0% lower rate in the Asian ($p = 0.043$) women compared to the other racial/ethnic groups (Table 3). This differential increase in DXA Abd-Fat and WC attributable to race/ethnicity in women can be seen as differences in the slopes of the respective race/ethnicity regression lines in Figure 1. Also, since proportional differences grow larger in terms of the original units as the values of the independent variable increase, the regression lines tend to diverge as WC increases.

Paragraph Number 11

For the men, Model 1 included WC, WC squared (WC^2), and height were significantly related to $\ln_{(Abd-Fat)}$ (Table 4). Race/ethnicity and the interactions of race/ethnicity and WC significantly improved model fit ($p < 0.001$). After statistically adjusting for the effects of height, average DXA Abd-Fat was higher for a given WC in the Asian-Indian (12.6%, $p = 0.044$) and Asian men (15.4%, $p = 0.001$) and lower in the AA men (-12.7% , $p < 0.001$) compared to the NHW men (Table 4). For a 1-cm increase in WC, DXA Abd-Fat increased at a 0.6% higher rate in the AA men ($p = 0.004$) and a 0.8% lower rate in the Asian-Indian ($p = 0.023$) men compared to the other racial/ethnic groups (Table 4). This differential increase in DXA Abd-Fat attributable to race/ethnicity in men can be seen as differences in the slopes of the respective race/ethnicity regression lines in Figure 2. Similar to the women's models, the regression lines diverged as WC increases.

Paragraph Number 12

The differential effects of race/ethnicity were most notable as the race/ethnicity-specific regression lines began to diverge at WC values between 90 cm and 100 cm in the women and about 100 cm in the men (Figures 1 and 2). For example, the Asian-Indian women have higher DXA Abd-Fat compared to Hispanic women at WC less than 90 cm, but at WC values greater than 90 cm the Asian-Indian women have higher DXA Abd-Fat. Similarly, the Asian-Indian men have higher DXA Abd-Fat compared to NHW men at WC less than 100 cm, but at WC values greater than 100 cm the Asian-Indian men had lower DXA Abd-Fat than NHW men.

Discussion

Paragraph Number 13

The LMM results showed that using WC to estimate DXA Abd-Fat resulted in biased estimates for the racial/ethnic groups studied unless race/ethnicity is included in the equation. After accounting for height and WC, DXA Abd-Fat was lower in the AA women and higher in the Hispanic and Asian-Indian women compared to the NHW women reference group. In men, DXA Abd-Fat was higher in the Asian-Indian and Asian groups and lower in the AA men relative to the NHW men reference group. We also found several differential racial/ethnic biases. Within women, the difference in DXA Abd-Fat per 1-cm difference in WC was lower in the Asian and Asian-Indian groups compared to the other race/ethnic groups. Within men, the difference in DXA Abd-Fat for a 1 cm difference in WC was lower in the Asian-Indian group and higher in the AA group compared to the other race/ethnic groups.

Paragraph Number 14

The WC values at which the racial/ethnic equations begin to diverge, 90 to 100 cm for women and 100 cm for men, are consistent with the definition of abdominal obesity currently used in the United States for women (88 cm) and men (102 cm) (16), although the International Diabetes Federation recommends several race/ethnicity-specific values that are 5 to 10 cm lower than these U.S. definitions (10). Abdominal obesity is strongly associated with risk of various chronic diseases, including cardiovascular disease and diabetes (10, 15). These results suggest that the risk attributable to abdominal obesity as defined by WC may differ among different racial/ethnic groups.

Paragraph Number 15

The finding that race/ethnicity affects the relationship between WC and abdominal fat is consistent with previous reports (1–2, 14, 22, 24). For example, the HERITAGE family study utilized computed tomography (CT) scanning to measure abdominal compartment body fat in NHW and AA men and women, ages from 17 to 65 y. Stanforth and associates (22) reported that for both men and women, with age, BMI, and WC statistically controlled, the abdominal visceral fat of AA men and women was significantly lower than NHW men and women, similar to our results, as well as those of others (1–2). The observation of higher fat in the abdominal region among Asian men and women relative to NHW and other races/ethnicities has also been reported previously (14), although our analysis is unique in that it evaluated nonlinear trends and interaction effects and found a complex effect of race/ethnicity on the relation of WC to DXA Abd-Fat. These TIGER results allow the generalization of race/ethnicity effects on the relation between WC and abdominal fat to NHW, AA, Hispanic, Asian, and Asian-Indian young adults.

Paragraph Number 16

While the TIGER results are consistent with prior studies, there are important differences. First, abdominal visceral fat of the TIGER subjects was measured with DXA while most of the prior studies used CT. The major limitation of DXA is that it does not differentiate subcutaneous and visceral abdominal fat stores. While CT is considered the “gold standard” for visceral fat mass, DXA now is the most common method used to measure body composition (9). Second, the data of the prior studies were cross-sectional while the TIGER data were longitudinal with subjects having from one to three measurements over 30 weeks. The statistical model used to evaluate the data in this study provided a means of examining the relation of DXA Abd-Fat and WC within an individual subject and accounting for various individual characteristics such as height and race/ethnicity (18, 25).

Paragraph Number 17

We explored random coefficient models including WC as a random effect to evaluate individual differences in the relation of WC with DXA Abd-Fat, but none of those approaches improved model fit. After accounting for race/ethnicity on the relation of WC with DXA Abd-Fat, within-subject effects on the WC to DXA Abd-Fat relation were minimal. We also explored BMI models for both men and women, and these models included significant race/ethnicity and race/ethnicity by BMI interaction effects, indicating that the bias in estimating DXA Abd-Fat using BMI without accounting for race/ethnicity introduces biases similar to those in our WC models. This has been shown previously with these TIGER data using BMI to estimate total body DXA percent fat (11).

Paragraph Number 18

The strengths of the current study are the use of large samples of men and women, the inclusion of multiple tests over 30 weeks, and the inclusion of multiple racial/ethnic groups. A limitation of this study is that the TIGER subjects are not a random sample of the U.S. population. The TIGER subjects were self-selected college-aged students who elected to participate in the study for which they received college course credit. Nevertheless, the TIGER men and women are a reasonable representation of the population of young adults, with overweight and obesity prevalence similar to national norms (17).

Paragraph Number 19

In summary, the present study confirms the generalizability of racial/ethnic body composition differences. There is a racial/ethnic bias when estimating DXA Abd-Fat with WC. This bias includes both a constant difference between some of the race/ethnicity groups and a differential race/ethnicity effect for some groups that is a function of the value of WC. The race/ethnicity group bias increases when WC is greater than about 90 cm in women and 100 cm in men. These data show that WC is associated with DXA Abd-Fat of both men and women, but using WC to estimate DXA Abd-Fat without accounting for race/ethnicity group results in bias estimates of DXA Abd-Fat with diverse young adults.

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Figure 1. Relation of waist circumference (WC) to DXA abdominal fat among young adult women. The regression lines are truncated to match the observed range of WC in the respective race/ethnicity groups.

Figure 2.

Relation of waist circumference (WC) to DXA abdominal fat among young adult men. The regression lines are truncated to match the observed range of WC in the respective race/ethnicity groups. The Hispanic men's regression equation did not differ from the equation for the NHW men referent group, so both groups are shown as a single line.

Table 1
Baseline characteristics of the TIGER women contrasted by racial/ethnic group.

Variable	Non-Hispanic White		Hispanic		African-American		Asian-Indian		Asian		All Women	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Observations, n	223		189		270		30		59		771	
Age, y	21.3	2.9	21.3	2.8	21.0	3.3	21.3	1.8	21.1	2.4	21.2	3.0
Height, cm	164.5 ^a	6.7	159.4 ^a	5.8	163.8 ^a	6.4	156.2 ^a	6.1	156.5 ^a	6.1	162.1	6.9
Weight, kg	68.9 ^b	17.1	66.8 ^b	15.4	73.4 ^b	20.2	59.0 ^b	13.1	55.8 ^b	12.6	68.6	18.1
Body mass index (BMI), kg/m ²	25.4 ^c	6.0	26.3 ^c	5.7	27.3 ^c	6.9	24.2	4.9	22.7 ^c	4.3	26.0	6.3
Waist Circumference, cm	76.8 ^d	13.2	78.0 ^d	11.4	79.0 ^d	15.1	71.7	9.6	69.8 ^d	9.4	77.1	13.3
DXA total body fat, %	31.4 ^e	7.4	34.1 ^e	6.5	31.5 ^e	8.1	36.0 ^e	5.3	31.0 ^e	5.8	32.3	7.4
DXA abdominal fat, g	2,050 ^f	1,661	2,323 ^f	1,363	2,136 ^f	1,697	1,977 ^f	872	1,543	803	2,105	1,539
ln(DXA abdominal fat), ln(g)	7.4	0.7	7.6	0.6	7.4	0.7	7.5	0.5	7.2	0.5	7.4	0.7

^a Hispanic, Asian-Indian, Asian < Non-Hispanic White, African-American (p<0.001).

^b Asian-Indian, Asian < Non-Hispanic White, Hispanic (p<0.001); Hispanic < African-American (p=0.003).

^c Asian < Hispanic, African-American (p=0.030); African-American < Non-Hispanic White (p=0.025).

^d Asian < Non-Hispanic White, African-American, Hispanic (p=0.010).

^e Non-Hispanic White, African-American < Hispanic (p=0.010); African-American < Asian-Indian (p=0.040).

^f Asian < Hispanic (p=0.021).

Table 2

Baseline characteristics of the TIGER men contrasted by racial/ethnic group.

Variable	Non-Hispanic White		Hispanic		African-American		Asian-Indian		Asian		All Men	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Observations, n	186		123		107		24		44		484	
Age, y	22.1	3.3	21.5	2.6	20.9	2.8	22.7	3.8	21.5	2.5	21.7	3.0
Height, cm	177.3 ^a	6.2	173.0 ^a	6.4	177.1 ^a	7.3	172.6 ^a	5.7	171.4 ^a	6.7	175.4	6.9
Weight, kg	85.2	18.9	83.5	20.2	86.2 ^b	21.0	77.0 ^b	20.6	77.9	19.3	83.9	19.9
Body mass index (BMI), kg/m ²	27.1	5.5	27.8	5.9	27.5	6.2	25.8	6.2	26.4	5.6	27.2	5.8
Waist Circumference, cm	89.5	14.6	90.1	15.5	84.1	15.0	86.2	16.7	84.4	14.6	87.9	15.2
DXA total body fat, %	21.2 ^c	7.8	21.9 ^c	7.3	17.0 ^c	8.7	23.8 ^c	9.5	20.7 ^c	7.6	20.5	8.2
DXA abdominal fat, g	2,018	1,554	2,201 ^d	1,757	1,477 ^d	1,636	1,933	1,409	1,879	1,654	1,925	1,642
ln(DXA abdominal fat), ln(g)	7.3	0.7	7.4	0.7	6.9	0.9	7.3	0.8	7.3	0.8	7.2	0.8

^a Hispanic, Asian-Indian, Asian < Non-Hispanic White, African-American (p<0.001).^b Asian-Indian < African-American (p=0.046).^c African-American < Non-Hispanic White, Hispanic, Asian-Indian, Asian (p=0.003).^d African-American < Hispanic (p=0.014).

Table 3

Maximum likelihood linear mixed models analysis examining the effects of race on the relation between ln-transformed abdominal fat and grand mean-centered waist circumference (WC-76.5 cm) in young adult women.

	Model 1		Model 2	
	Est	SE	Est	SE
Fixed Effects				
Constant	9.208**	0.230	8.506**	0.242
15-Week Test	0.028*	0.010	0.028**	0.010
30-Week Test	-0.036**	0.013	-0.036**	0.013
Height	-0.010**	0.001	-0.005**	0.001
WC-76.5	0.048**	0.0008	0.050**	0.001
(WC-76.5) ²	-0.0005**	0.00003	-0.0005**	0.00003
Hispanic			0.086**	0.026
African-American			-0.078**	0.023
Asian-Indian			0.219**	0.059
Asian			0.052	0.046
Hispanic × (WC-76.5)			-0.003	0.002
African-American × (WC-76.5)			0.002	0.002
Asian-Indian × (WC-76.5)			-0.010*	0.004
Asian × (WC-76.5)			-0.007*	0.003
Random Effects				
SD (Intercept)	0.246	0.008	0.230	0.008
SD (Residual)	0.135	0.004	0.135	0.004

* p<0.05.

** p<0.01.

Likelihood ratio (LR) test comparing Model 2 to Model 1: $\chi^2(8) = 88.37$, $p < 0.001$.

Table 4

Maximum likelihood linear mixed models analysis examining the effects of race on the relation between ln-transformed abdominal fat and grand mean-centered waist circumference (WC-86.8 cm) in young adult men.

	Model 1		Model 2	
	Est	SE	Est	SE
Fixed Effects				
Constant	8.996**	0.332	8.391**	0.334
15-Week Test	0.038**	0.013	0.037**	0.012
30-Week Test	-0.031	0.018	-0.034	0.018
Height	-0.010**	0.002	-0.006**	0.002
WC-86.8	0.057**	0.001	0.055**	0.001
(WC-86.8) ²	-0.0005**	0.00003	-0.0005**	0.00003
Hispanic			0.054	0.032
African-American			-0.136**	0.033
Asian-Indian			0.119*	0.059
Asian			0.143**	0.045
Hispanic × (WC-86.8)			-0.001	0.002
African-American × (WC-86.8)			0.006**	0.002
Asian-Indian × (WC-86.8)			-0.008*	0.003
Asian × (WC-86.8)			-0.0002	0.003
Random Effects				
SD (Intercept)	0.258	0.010	0.239	0.010
SD (Residual)	0.141	0.006	0.139	0.005

* p<0.05.

** p<0.01.

Likelihood ratio (LR) test comparing Model 2 to Model 1: $\chi^2(8) = 74.15$, $p < 0.001$.