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PAPER

The effect of sex, age and race on estimating percentage body fat from body mass index: The Heritage Family Study

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OBJECTIVE: To study the effects of sex, age and race on the relation between body mass index (BMI) and measured percent body fat (%fat).
DESIGN: Cross-sectional validation study of sedentary individuals.
SUBJECTS: The Heritage Family Study cohort of 665 black and white men and women who ranged in age from 17 to 65 y.
MEASUREMENTS: Body density determined from hydrostatic weighing. Percentage body fat determined with gender and race-specific, two-compartment models. BMI determined from height and weight, and sex and race in dummy coded form.
RESULTS: Polynomial regression showed that the relationship between %fat and BMI was quadratic for both men and women. A natural log transformation of BMI adjusted for the non-linearity. Test for homogeneity of log transformed BMI and gender showed that the male–female slopes were within random variance, but the intercepts differed. For the same BMI, the %fat of females was 10.4% higher than that of males. General linear models analysis of the women's data showed that age, race and race-by-BMI interaction were independently related to %fat. The same analysis applied to the men's data showed that %fat was not just a function of BMI, but also age and age-by-BMI interaction. Multiple regression analyses provided models that defined the bias.
CONCLUSIONS: These data and results published in the literature show that BMI and %fat relationship are not independent of age and gender. These data showed a race effect for women, but not men. The failure to adjust for these sources of bias resulted in substantial differences in the proportion of subjects defined as obese by measured %fat.
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Keywords: body composition; body mass index; overweight; obese

Introduction

Public health data document that American adults and youth are getting heavier. The weight-height ratio, body mass index (BMI), has become the variable used to define standards of overweight and obesity. The advantage of using BMI is that height and weight are variables readily available and easy to measure. The 1985 NIH Consensus Development Panel defined obesity of American men and women at a BMI of ≥ 27.8 and $\geq 27.3\,kg/m^2$, respectively. These earlier BMI obesity standards represented the sex-specific 85th percentile of the BMI distribution for persons in the 20–29 y age group.[1,2] The World Health Organization (WHO) recently published BMI-based overweight and obesity standards for men and women.[3] The WHO standard defined a pre-obese state (overweight) as a BMI between 25 and $29.9\,kg/m^2$ and obesity as a BMI $\geq 30\,kg/m^2$. The use of a single standard for

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obesity for all adults was recommended because it is thought to be independent of age and reference population and can be used for making comparisons across studies both in the United States and internationally.[1] The WHO standards were adopted subsequently by a National Institutes of Health panel.[4]

The practice of using a single BMI standard assumes that the BMI is independent of variables such as age, sex, ethnicity, and level of physical activity. Gallagher and associates[5] presented evidence that BMI-defined levels of adiposity determined from percentage body fat (%fat) were independent of race (black *vs* white), but not age and gender. Their multivariate analysis showed that age and gender accounted for significant %fat variance beyond that attributed to BMI. Other investigators have documented that the relationship between anthropometric measures (BMI and skinfold fat) and measured %fat were not independent of age and gender[6–9] or ethnicity.[6,8,10] The goal of this study was to examine the effects of sex, age and race on the relation between BMI and measured %fat.

Methods

These data were obtained as a part of the Heritage Family Study which is a large multicenter clinical trial investigating the possible genetic basis for the variability in the responses of physiological measures, and the risk factors for cardiovascular disease and type 2 diabetes mellitus, to endurance exercise training. This study includes four Clinical Centers (Indiana University (note: this Clinical Center was formerly at Arizona State University), Laval University in Quebec where the Consortium Coordinating Center was, but has moved to the Pennington Biomedical Research Center (Baton Rouge, Louisiana), the University of Minnesota, and The University of Texas at Austin) and a Data Coordinating Center (Washington University School of Medicine, St Louis, MO). Details of the Heritage Family Study aims, experimental design, and measurement protocols have been presented in detail in a previous publication.[11]

The Heritage Family Study sample consists of families, including the natural father and mother (≤ 65 y of age) and generally three offspring 17 y of age or older for white families, or at least two first-degree relatives for black families. Inclusion and exclusion criteria have been summarized in detail in a prior publication.[11] Participants were screened by each Clinical Center's supervising physician and staff, and only those who were previously sedentary, free from pre-existing disease and not taking any medications that would affect any of the outcome variables were allowed to enter the study. The Heritage Family Study started with 855 subjects, and a total of 742 completed the study. The sample of this study included 655 subjects who had complete body composition data at the start of the study. The sample included 296 men (81 black and 215 white) and 359 women (121 black and 238 white).

The anthropometric and body composition test battery was administered on a single day. The participants reported to the laboratory at least 4 h post-prandial and had performed no exercise in the previous 4 h. They were then measured for height and weight, residual lung volume, and underwater weight. Stature and body mass were measured to the nearest 0.1 cm and 0.1 kg with a balance beam scale and a stadiometer. BMI was determined as the ratio of weight (kg) and height^2 (m). Hydrostatic weighing was used to assess body density according to the method of Behnke and Wilmore.[12] The body density methods are fully described in another source.[13] Relative body fat (%fat) was estimated from body density using the equations of Siri[14] for white men, Lohman[15] for Caucasian women, Schutte *et al*[16] for black men, and Ortiz *et al*[17] for black women. Important quality assurance and quality control procedures were instituted across all four Clinical Centers and have been described in other sources.[13,18]

The independent variables of this study were BMI, sex, age and race. BMI and age were continuous variables, while race and sex were dummy coded; race, black = 0 and white = 1; and sex, female = 0, male = 1. Race differences were evaluated with ANOVA. Polynomial regression analysis examined the linearity of the BMI and %fat relationship. General linear model analysis was used to examine the relationship between the dependent variable, hydrostatically measured %fat, and the independent variables. A step-down analysis was used to determine if the independent variables and their interactions accounted for %fat variance beyond that of BMI. A *post-hoc t*-test determined if the regression weight of each independent variable differed significantly from zero.[19,20]

Cross-validation analysis was used to examine the generalizability of the Heritage data and body composition methodology. Published BMI, age and gender prediction equations were applied to the Heritage data. Table 1 gives these equations. The Gallager equation[5] was developed on a sample of 706 black and white men and women who ranged in age from 20 to 94 y. The dependent variable was %fat determined with the four-compartment model. The Deurenberg *et al* equation,[7] developed on 747 Dutch men and women, used the two-compartment Siri equation to calculate fat. The third published equation[8] was a meta analysis of 46 studies consisting of a total 2516 and 1976 white men and women. The final equation was developed with the Jackson–Pollock data[21,22] that used the Siri two-compartment method to determine %fat. The database consisted of 679 men and women who were predominately white. This equation has not been reported in the literature.

Each equation in Table 1 was applied to the Heritage data to estimate each individual's %fat. Data fit was determined by comparing estimated %fat with Heritage measured %fat contrasting race and gender groups. Product–moment correlation determined the relationship between estimated and measured %fat. Systematic bias was evaluated by determining the mean between measure and estimated $(Y\text{-}\hat{Y})$ %fat and determining if the difference differed from the expected

Table 1 Regression equations with functions to estimate percentage body fat from BMI, age and sex

		Regression model					
Study	n	*BMI*	*Sex*	*Age*	*Intercept*	r^2	*s.e.e.*
Gallagher *et al*[5]	706	1.46	− 11.6	0.14	− 10.0	0.81	5.7
Deurenberg *et al*[7]	747	1.20	− 10.8	0.23	− 5.4	0.79	4.1
Deurenberg *et al*[8]	*	1.29	− 11.4	0.20	− 8.0	0.88	2.2
Jackson – Pollock[22,23]	679	1.61	− 12.1	0.13	− 13.9	0.75	5.5

[a]Meta analysis of 46 studies with white men and women. All values are based on study means, not individual values.

value of 0. The standard error of estimate (s.e.e.) equation[23] used was:

$$\text{s.e.e.} = \sqrt{\frac{\sum(\text{measured} - \text{estimated})^2}{n-1}}$$

Results

Table 2 gives the descriptive statistics of the male and female subjects contrasted by race. The data show the well-documented anthropometric and body composition gender differences. The men were taller, heavier and leaner than the women. ANOVA was used to evaluate race differences for each gender. This analysis showed that the only male race difference was body density. The density of the black men was significantly higher than that of the white men. When converted to %fat using race-specific equations, the black and white difference was small, only 0.1%. In contrast, there were several significant female race differences. The %fat (mean ± s.d.) of the black women was 6% higher than that of the white women (36.0 ± 8.9 *vs* 30.0 ± 9.8), and their body weight was 7.9 kg higher (74.4 ± 16.5 *vs* 66.5 ± 13.8). This weight difference was due to the difference in fat weight. The mean difference in fat weight was 7.0 kg (28.0 ± 12.4 *vs* 21.0 ± 11.0). The women's race difference in fat-free body mass (FFW) of 0.9 kg was not statistically significant.

Regression analysis was used to examine the bivariate relationship between measured %fat and BMI. Figure 1 is the plot of the male and female data. An examination of these scattergrams suggested that the relationship between BMI and %fat was not linear. Polynomial regression was used to test for linearity. The BMI linear component accounted for 74.5% of the female variance and 65.4% for the male variance. Adding the quadratic component accounted for an additional 3.9% of the female variance ($F_{(1356)} = 64.97$; $P < 0.01$) and 2.2% of the male variance ($F_{(1293)} = 19.58$; $P < 0.01$). This showed that the relationship between BMI and %fat for the Heritage males and females was quadratic. The female model ($r^2 = 0.78$, s.e.e. = 4.6%) provided a slightly more accurate fit than the male model ($r^2 = 0.68$, s.e.e. = 4.9%).

The BMI data were transformed to the natural logarithm scale to minimize the non-linearity.[20] Table 2 gives the log transformed BMI descriptive statistics. Figure 1 includes the male and female quadratic regression lines, which appear to be parallel. This was examined by testing for homogeneity of male and female slopes and intercepts of the log BMI and %fat relationship.[19] This analysis showed that the test for slope was not statistically significant ($F_{(1654)} = 0.95$; $P > 0.05$), but the intercepts were ($F_{(1654)} = 759.02$; $P < 0.01$). The non-significant gender effect in slopes showed that the male and female differences in the rate of incremental change in %fat associated with an increment in log BMI were within chance variation. The significant difference in intercepts showed

Table 2 Male and female sample characteristics (mean ± s.d.) contrasted by race

	Males (n = *296*)		*Females* (n = *359*)	
Variable	*Black* (n = *81*)	*White* (n = *215*)	*Black* (n = *121*)	*White* (n = *238*)
Age (y)	34.3 ± 12.0	36.5 ± 15.1	32.8 ± 11.4	34.4 ± 13.8
Height (cm)	176.1 ± 6.7	177.6 ± 6.3	162.6 ± 6.2	163.9 ± 6.4
Weight (kg)	83.7 ± 16.8	83.8 ± 15.6	74.4 ± 16.5	66.5 ± 13.8[a]
BMI (weight/height^2)	26.9 ± 4.8	26.5 ± 4.7	28.1 ± 6.1	24.8 ± 4.9[a]
ln (BMI)	3.28 ± 0.17	3.26 ± 0.17	3.31 ± 0.22	3.19 ± 0.18[a]
Body density (kg/l)	1.052 ± 0.018	1.047 ± 0.020[b]	1.022 ± 0.019	1.029 ± 0.021[a]
Percentage fat (%)	22.9 ± 7.3	23.0 ± 9.0	36.0 ± 8.9	30.0 ± 9.8[a]
Fat weight (kg)	20.1 ± 10.0	20.2 ± 10.9	28.0 ± 12.4	21.0 ± 11.0[a]
Fat-free weight (kg)	63.6 ± 8.7	63.5 ± 7.7	46.4 ± 5.6	45.5 ± 5.2

[a]$P < 0.01$; [b]$P < 0.05$.

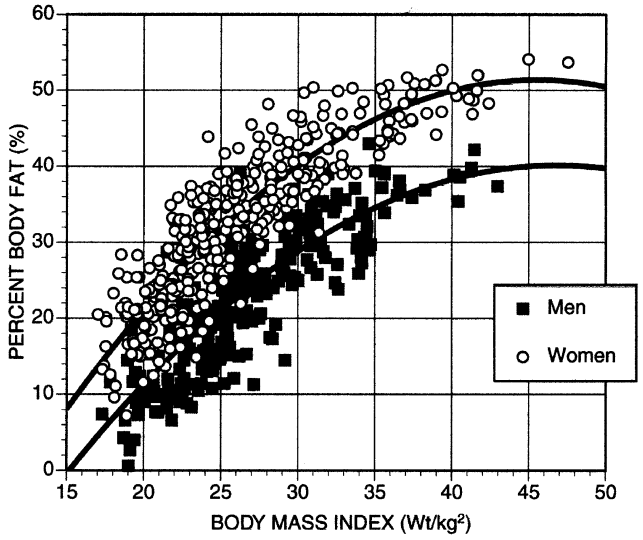

Figure 1 Non-linear plot of the relationship between BMI and measured percentage body fat of the male and female Heritage data. The quadratic regression equations are: women, $Y'_{(\%fat)} = (4.35 \times BMI) - (0.05 \times BMI^2) - 46.24$, ($r^2 = 0.78$, s.e.e. = 4.63%); and men, $Y'_{(\%fat)} = (3.76 \times BMI) - (0.04 \times BMI^2) - 47.80$, ($r^2 = 0.68$, s.e.e. = 4.90%).

that, for the same BMI, the %fat of females was about 10.4% higher than that of males.

General linear models examined the effect of age, race and the log transformed BMI on measured %fat. The male and female data were analyzed separately. Table 3 gives these analyses. Model I is the regression equation for log transformed BMI and %fat. The r^2 estimates for model I were nearly identical to those obtained in the polynomial regression models showing that the log transformation provided a good fit of the non-linear relationship. Model II added age to the model, and it accounted for an additional 5% of male variance ($F_{(1293)} = 50.51$; $P < 0.01$) and 3% of female variance ($F_{(1356)} = 54.19$; $P < 0.01$). Next (model III) race was added to the independent variables of age and log transformed BMI variable. The dummy coded race variable was statistically significant for the female model ($\Delta r^2 = 0.01$, $F_{(1355)} = 10.13$; $P < 0.01$), but not for the males ($\Delta r^2 < 0.01$, $F_{(1292)} < 1.00$; $P > 0.05$). The final step of the general linear model analyses (model IV) was to examine the interaction of the significant independent variables. This analysis showed that the female race by log transformed BMI interaction was statistically significant ($\Delta r^2 = 0.0051$, $F_{(1354)} = 9.84$; $P < 0.01$). The men's age by log transformed BMI interaction was statistically significant ($\Delta r^2 = 0.01$, $F_{(1292)} = 12.83$; $P < 0.01$).

The female and male interactive effects were examined by comparing the differences between measured %fat and %fat estimated with model II, which did not include the interaction terms. Table 4 gives these mean difference (± s.d.) between measured and estimated %fat (ie residual score). The means are contrasted by the WHO BMI groups and the interaction variable. The source of the female race by BMI interaction is for the BMI group $< 25\,kg/m^2$. With age statistically controlled, log transformed BMI systematically under estimated the measured %fat of black women by 2.0 %fat and over estimated %fat of white women by 0.8 %fat. As BMI increased, the race difference became progressively smaller. The age by BMI interactive effect of men was examined by splitting the men's sample into three age groups. The male interactive effect was in the WHO obesity group ($BMI > 30\,kg/m^2$). The mean (± s.d.) differences between measured and estimated (model II) %fat for age the groups were: < 30 y, 3.3 ± 4.3; 30 – < 45 y, -0.1 ± 3.9; and ≥ 45 y, -1.3 ± 3.7. The mean differences for the older two male age groups were < 1.0 %fat.

Table 5 gives the cross-validation of the four equations (Table 1) applied to the Heritage data. This analysis examined the equation's accuracy contrasted by gender and race. The product-moment correlations among the four methods were nearly identical. The largest correlation difference was 0.02 units. The correlations for the female subjects were consistently higher than the male coefficients. The correlations for black men were slightly lower than the coefficients for white men, but the standard errors were similar. This suggested that the differences in the cross-validation correla-

Table 3 General linear model analyses examining the effect of log transformed BMI, age, race and interactions on percentage body fat of females and males

	Female models				*Male models*			
Variable	*I*	*II*	*III*	*IV*	*I*	*II*	*III*	*IV*
Intercept	−107.22[a]	−102.01[a]	−97.11[a]	−82.83[a]	−111.13[a]	−103.94[a]	−104.21[a]	−149.24[a]
ln BMI	43.05[a]	39.96[a]	38.67[a]	34.43[a]	41.04[a]	37.31[a]	37.35[a]	51.31[a]
Age		0.14[a]	0.15[a]	0.14[a]		0.14[a]	0.14[a]	1.47[a]
Race[b]			−1.63[a]	−26.02[a]			−0.23	
Race×ln BMI				7.48[a]				
Age×ln BMI								−0.41[a]
r^2	0.78[a]	0.80	0.81[a]	0.82[a]	0.67[a]	0.72[a]	0.72[a]	0.73[a]
$r^2\Delta$		0.01[a]	0.01[a]	0.01[a]		0.05[a]	0.00	0.01[a]
s.e.e. (% fat)	4.7	4.4	4.3	4.3	4.9	4.6	4.6	4.5

[a]$P < 0.001$. [b]Key: race — black = 0 and white = 1.

Table 4 Mean (±s.d.) between measured and estimated (model II) percentage body fat contrasted by gender, WHO BMI groups, and interaction terms (model IV)

	Women — race groups		*Men — age groups*		
BMI group (kg/m²)	*Black*	*White*	*< 30 y*	*30 – < 45 y*	*≥ 45 y*
< 25	2.0 ± 4.1[a]	− 0.8 ± 4.8[b]	− 0.5 ± 4.8	− 0.2 ± 3.4	0.0 ± 4.8
	n = 45	*n* = 143	*n* = 85	*n* = 10	*n* = 23
25 – < 30	0.9 ± 4.4	0.3 ± 4.0	− 0.9 ± 5.3	0.3 ± 4.3	0.7 ± 4.1
	n = 33	*n* = 45	*n* = 29	*n* = 34	*n* = 34
≥ 30	− 0.1 ± 3.4	− 0.4 ± 3.6	3.3 ± 4.3[a]	− 0.1 ± 3.9	− 1.3 ± 3.7[c]
	n = 43	*n* = 34	*n* = 20	*n* = 16	*n* = 29
All	1.0 ± 4.0	− 0.5 ± 4.5	0.0 ± 5.0	0.1 ± 4.0	0.0 ± 4.2
	n = 121	*n* = 238	*n* = 143	*n* = 60	*n* = 102

[a]$P < 0.01$; [b]$P < 0.05$; [c]$P = 0.06$.

Table 5 Cross-validation of published equations with the male and female Heritage subjects

	Black			*White*		
BMI, age and gender model	$r_{yy'}$	*Y-Y′ (±s.d.)*	*s.e.e.*	$r_{yy'}$	*Y-Y′ (±s.d.)*	*s.e.e.*
Male sample (n = 296)						
Gallagher *et al*[5]	0.81	0.4 ± 4.6	4.6	0.86	0.7 ± 4.7[b]	4.7
Deurenberg *et al*[7]	0.79	− 1.1 ± 4.6[b]	4.7	0.85	− 1.1 ± 4.8[b]	4.9
Jackson and Pollock[22,23]	0.81	0.1 ± 4.9	4.9	0.86	0.4 ± 4.8	4.8
Deurenberg *et al*[8]	0.80	0.7 ± 4.5	4.5	0.85	0.7 ± 4.7[b]	4.8
Female sample (n = 359)						
Gallagher *et al*[5]	0.89	0.3 ± 4.3	4.8	0.88	− 1.1 ± 4.7[a]	4.3
Deurenberg *et al*[7]	0.88	0.1 ± 4.2	4.2	0.88	− 2.3 ± 4.8[a]	5.4
Jackson and Pollock[22,23]	0.89	− 0.6 ± 4.8	4.8	0.88	− 1.6 ± 4.7[a]	4.9
Deurenberg *et al*[8]	0.89	1.0 ± 4.2[a]	4.8	0.88	− 1.0 ± 4.7[a]	4.3

[a]$P < 0.01$; [b]$P < 0.05$.

tions were due to the higher %fat variability of the white men (Table 2). Except for the Deurenberg *et al* equation applied to white men, the mean difference between measured and estimated %fat was < 2 %fat, and nine of the 16 differences were < 1 %fat. All four equations systematically overestimated measured %fat of white women. These mean differences ranged from − 2.3 to − 1.0. With the exception of the Deurenberg *et al* s.e.e. of 5.4 %fat, all cross-validation s.e.e. values were ≤ 4.9 %fat.

Discussion

These Heritage results showed that several factors affect the relationship between BMI and measured %fat. The polynomial regression analysis documented that the relationship between BMI and %fat was quadratic, not linear. This curvilinear trend was common to both the male and female data. Gallagher *et al*[5] tested for non-linearity and found that the BMI and %fat relationship was linear, not quadratic. This incongruence between studies is likely because of differences in the BMI range of the two samples. The upper BMI inclusion range used in the Gallagher study was ≤ 35 kg/m². Although the Heritage subjects were preferentially selected to have a BMI < 40 kg/m², subjects with levels above 40 kg/m² were included so long as they were deemed medically fit for the training program. These subjects were judged by the supervising physician to be 'healthy' and able to meet the exercise demands required in the Heritage study. There were 15 Heritage subjects (six men and nine women) with BMI values > 40 kg/m². The highest female BMI was 47.5 kg/m² compared to 43.0 kg/m² for men. An examination of the data in Figure 1 documents the influence of BMI values ≥ 35 kg/m² on the curvilinear relationship.

Gallager and associates[5] reported that race (black and white) did not statistically influence the relationship of BMI and %fat for either men or women. These Heritage results found a race effect for women, and it interacted with BMI. An examination of the mean difference between measured %fat and %fat estimated with Model II (Table 4) showed that the source of race bias was for lower BMI values, below the WHO pre-obese standard of 25 kg/m². Not accounting for race produced an under estimate of measured %fat of black women and over estimate the %fat of white women for BMI values below 25 kg/m². This small effect became smaller as a women's BMI approached the WHO obesity standard of 30 kg/m². The cross-validation of the Gallagher *et al*[5] equation on the Heritage women provided a good fit of the black and white Heritage women. The

cross-validation standard error of black women was slightly higher than for white women (4.8 *vs* 4.3 %fat) and both were lower than the 5.7 %fat validation s.e.e. reported by Gallagher and associates. These results suggested that the Heritage women's race effect was small and not a major source of variance when classifying women as obese by the WHO standard.

A common finding among all regression models in Table 1 was that age, gender and BMI regression coefficients were similar. The Heritage data were reanalyzed to duplicate the BMI, age and gender regression equations provided in Table 1. The regression weights ($b \pm 95\%$ CI) for the Heritage sample were: BMI (1.39 ± 0.08); age (0.16 ± 0.03); and sex (-10.34 ± 0.72). These Heritage regression coefficients are similar to those given in Table 1. This shows that sex and age are major sources of variation in the BMI and %fat relationship. The gender effect in body composition is well documented.[5,7–9,21,22] The age by BMI interaction for men is a new finding. The *post-hoc* analysis provided in Table 4 shows that this interactive effect was due to the an over estimate of %fat of younger men with a BMI $> 30\,kg/m^2$. A possible explanation for the interaction is the inter-relationship among age, physical activity and body composition. Cross-sectional aging research[24] showed that both physical activity level and FFM decreased with age. Pollock and associates[25] reported a longitudinal decline in the FFM of active master athletes. Fleg and Lakatta[26] reported that at least 50% of the age-related decline in aerobic fitness was do to the loss of muscle mass. This suggests that future research needs to consider the role of physical activity on the variation of FFM and how it influences BMI.

Published research suggests that the body composition race effect is complex. Wagner and Heyward[27] published a review article comparing body composition differences between black and white individuals. They reported that blacks have a greater bone density and body protein content than whites, which produces a higher density in FFM in Blacks. Visser *et al*[28] used the four-compartment model to calculate the %fat of 668 black and white men and women. These data came from the database used by Gallagher *et al*.[5] The Visser *et al* analysis showed that the mineral fraction of FFM of black men and women was significantly higher than in whites. They also reported that the water fraction of FFM of blacks was higher than in the white subjects, but that only the difference for women was statistically significant. The bone density and water fraction differences offset each other, producing non-significant race and gender differences in the density of FFM. The mean density of FFM of the gender and race groups ranged from 1.098 kg/l for white men to 1.101 kg/l for white women. None of these means were significantly different from 1.100 kg/l. Visser compared %fat estimates obtained with four- and two-compartment models. The mean ($\pm$ s.d.) %fat differences between the four- and two-compartment models ranged from a low of -0.1 %fat for black men age > 60 y to a high of 1.3 %fat for white women age 40–60 y. Visser *et al* reported that two-compartment models were valid for black and white men and women at a group level, but the four-compartment model should be used when evaluating individual differences.

While Visser and associates reported that density of FFM of black and white American men and women did not differ from 1.100 kg/l, published four-compartment data showed that the density of FFM of other ethnic groups differ. Deurenberg-Yap *et al*[10] reported significant differences in density of FFM of Chinese, Malays and Indians. The means ranged from a low of 1.0987 kg/l for Chinese men to a high of 1.1082 kg/l for Chinese women. Deurenberg *et al*[8] applied the meta analysis equation developed on white subjects (Table 1) to the group data of several different ethnic groups. They examined ethnic group variation with the mean difference between measured and estimated %fat. The mean differences for Chinese were small, ≤ 1 %fat, but the mean differences for the sample of Ethiopian men and women were large, 10.0 and 9.9 %fat. In contrast, the mean difference for black men and women was 1.9 %fat. The meta equation under estimated the %fat of Thai and Indonesian men and women. These mean differences ranged from 5.9 to 8.8 %fat. The meta equation over estimated the %fat Polynesian men (-4.1 %fat) and women (-3.9 %fat). The meta analysis results led Deurenberg and associates to suggest the need to use population-specific cut-off points for defining obesity from BMI.

The %fat of the Heritage subjects was determined by race- and gender-specific two-compartment %fat equations. This could be the reason for the interactive effects. To examine this possibility, the Heritage data were re-analyzed using body density as the dependent variable. This re-analysis showed that except for the expected difference in polarity of the regression coefficients, the %fat and body density results (model IV) were nearly identical. The female body density analysis yielded an r^2 of 0.80, compared to 0.82 for the %fat model. *Post hoc* analysis showed that like the %fat model, the regression coefficients of the independent variable of the body density model were all statistically significant, including the race-by-BMI interaction. The re-analysis of the men's data produced the same result. The r^2 of the men's body density model IV equation was only 1% lower than the %fat model and all regression coefficients, including the age by BMI interaction term, were statistically significant in the expected direction. This re-analysis showed that the race and interactive effects were not caused by using race-specific two-compartment %fat equations. The body density re-analyses results are supported by the cross-validation analysis of the Gallagher four-compartment model and the other three equations that used the two-compartment model (Table 5). With the exception of the Deurenberg equation,[7] the Gallagher cross-validation results were not noticeably superior to those obtained with the two-compartment %fat equations.

The data in Table 1 show that the age regression coefficients ranged from 0.13 to 0.23, suggesting a cross-sectional aging effect of about 1.5–2.0 %fat per decade. While this

may seem small, the bias can be substantial when defining the proportion of subjects in a population who would be classed as obese by a %fat standard. To examine this more closely, multiple logistic analysis[20,29] was used with the Heritage data to estimate the proportion of men and women, age 20 and 60 y, who would be classified as obese by %fat cut-off scores of ≥ 25 and $\geq 33\%$.[30] The proportion of women who would be expected to exceed 33 %fat at a BMI of 25 kg/m^2 ranged from 27% (age 20 y) to 79% for age 60 y. The proportion of women exceeding 33 %fat for a BMI of 30 kg/m^2 ranged from 86 to 98% for women aged 20 and 60. For the WHO overweight standard, the proportion men exceeding $\geq 25\%$ fat ranged from 12% at age 20 y to 44%, at age 60 y. The male range for a BMI of 30 kg/m^2 was 74–94%. This logistic analysis showed that age had a substantial effect on population estimates of obesity defined by measured %fat.

The WHO and NIH cut-off BMI values of 25 and 30 kg/m^2 to delineate overweight and obesity were defined because of the general trends in the relationships between BMI and morbidity and mortality rates. They were not arrived at because BMI was a perfect predictor of obesity. However, it is important to understand how BMI and adiposity, particularly %fat, associate across a wide range of ages, in each sex and among ethnic groups. The results of the present study indicate that BMI is only a moderate predictor of %fat. These Heritage results are consistent with the re-analysis of published data showing that the BMI and %fat relationship are not independent of gender and age. These Heritage results are consistent with published data showing the need to consider age and gender when defining the prevalence of obesity with BMI for populations of American men and women.

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