
Shankuan Zhu, ZiMian Wang, Wei Shen, Steven B Heymsfield, and Stanley Heshka

ABSTRACT

Background: Increasing attention has focused on the association between body fatness and related metabolic risk factors. The quantitative link between percentage body fat (%BF) and the risk of metabolic syndrome is unknown.

Objectives: The objectives were to determine the risk [odds ratios (ORs)] of metabolic syndrome based on %BF in black and white men and women in the United States and to provide corresponding ranges of %BF associated with a risk equivalent to body mass index (BMI; kg/m²).

Design: The subjects were participants in the third National Health and Nutrition Examination Survey and were divided into those with and without the metabolic syndrome. OR equations were derived from logistic regression models for %BF and BMI, with the 25th percentile in the study population as the reference. Ranges were developed by associating %BF with the equivalent risk of metabolic syndrome based on established BMI cutoffs.

Results: Four sets (men, women, black, and white) of OR curves were generated for %BF and for BMI by using data from 8259 adults. The ORs for metabolic syndrome were lower in blacks than in whites at any given %BF or BMI. The developed cutoffs for %BF differed between men and women but showed only small race and age effects. A simplified set of sex-specific %BF ranges for the risk of metabolic syndrome were developed.

Conclusions: The risk of metabolic syndrome can be established from measured %BF by using either the developed OR curves or %BF thresholds at traditional BMI cutoffs. This information should prove useful in both clinical and research settings. Am J Clin Nutr 2003;78:228–35.

KEY WORDS Cardiovascular disease, diabetes, obesity, body mass index, bioelectrical impedance analysis, odds ratio

INTRODUCTION

A link exists between body weight, health risks, morbidity, and mortality (1–3). High body weight, or more specifically a high body mass index (BMI; in kg/m²), is associated with several abnormalities now collectively referred to as the metabolic syndrome (4–7). Insulin resistance with excessive adiposity appears to be the central pathogenic factor in metabolic syndrome that additionally includes features such as elevated glucose concentrations and blood pressure, dyslipidemia, and upper body adiposity (6).

The risk of developing the metabolic syndrome increases strikingly above a BMI of ≈25 (1, 2). In a recent study, Park et al (7) reported a prevalence of metabolic syndrome in 4.8%, 22.8%, and 60.2% of normal-weight (BMI: 18.5–24.9), overweight (25.0–29.9), and obese (≥30) men in the US population. Prevalence rates were similar in US women.

Although BMI is a useful surrogate measure of adiposity, increasing interest is centering on actual measures of fatness and their link with health-related processes (8–14). Physiologic mechanisms are recognized that associate total and regional body fat with insulin resistance, glucose metabolism, serum lipid concentrations, and blood pressure.

Gallagher et al (14) developed a set of age- and sex-specific ranges for percentage body fat (%BF) based on BMI thresholds of 18.5, 25, and 30 for normal-weight, overweight, and obese classifications, respectively, established by the National Institutes of Health (NIH) and the World Health Organization (WHO). In their approach, Gallagher et al (14) derived %BF-prediction formulas based on BMI, sex, age, and race. These formulas were then used to calculate %BF at each of the BMI thresholds. A limitation of this approach is that %BF may have a different relation than does BMI to weight-related clinical conditions such as the metabolic syndrome. Although several other reports fill an important gap in the existing literature, none of the selected approaches generate %BF ranges associated with health risks such as the presence of metabolic syndrome (10, 15).

In this report we use a new strategy for deriving %BF ranges associated with the odds of meeting metabolic syndrome criteria. We first used a representative sample of US adults to generate odds ratio (OR) curves for the metabolic syndrome based on BMI and %BF measured by bioelectrical impedance analysis (BIA) (16) while controlling for other covariates, such as socioeconomic and lifestyle related factors. We then used these logistic

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See corresponding editorial on page 197.
regression models to calculate %BF thresholds with a risk of metabolic syndrome equivalent to the risk associated with 4 traditional BMI cutoffs.

SUBJECTS AND METHODS

Study design

Metabolic syndrome was defined according to the criteria of the National Cholesterol Education Program Adult Treatment Panel III (ATP III; 6), and the subject sample consisted of noninstitutionalized black and white adult participants in the third National Health and Nutrition Examination Survey (NHANES III, 1988–94). Subjects were divided into 2 groups according to the presence or absence of the metabolic syndrome. OR equations were then derived from logistic regression models for %BF and BMI, after adjustment for various socioeconomic and lifestyle factors, with the use of the 25th percentile in the study population as the reference. We then identified race- and sex-specific %BF cutoffs that had the same ORs for the metabolic syndrome as did NIH- and WHO-established BMI cutoffs for normal weight (BMI 18.5–24.9), overweight (25.0–29.9), obesity class I (30.0–34.9), and obesity class II (≥ 35.0) (1, 2). The developed %BF cutoffs thus identify the risk level of the metabolic syndrome that corresponds to that associated with traditional BMI cutoffs.

Study population

The study sample included black and white men and women who had participated in NHANES III. NHANES III was conducted by the National Center for Health Statistics to evaluate the health and nutritional status of the noninstitutionalized US population. The study was carried out at 89 locations in 2 phases: 1988–1991 and 1991–1994. NHANES III used stratified, multistage probability cluster sampling, and weights indicating the probability of being sampled were assigned to each respondent, which allowed the results to be representative of the US population. Detailed information on NHANES III is presented elsewhere (17).

We limited the subjects selected to those aged > 20 y in whom data on anthropometric variables, blood pressure, socioeconomic status, lifestyle-related information, blood studies, and BIA values had been collected. In NHANES III, the BIA procedure was not carried out in pregnant women or subjects with cardiac pacemakers. Of the 8259 subjects, we excluded 926 subjects who had consumed food or beverages other than water within 6 h before the venipuncture or BIA measurements and 19 women who were lactating at baseline. In addition, we also excluded 2 subjects whose BIA estimate of %BF was less than zero. Of the remaining 7312 participants, 2628 were black (1211 men, 1417 women) and 4684 were white (2238 men, 2446 women).

Percentage body fat estimated by bioelectrical impedance analysis

A body-composition analyzer for BIA (model 1990B; Valhalla Scientific, San Diego) was used for the measurement of wholebody electrical resistance and impedance. To minimize measurement errors, the NHANES data-collection process used well-defined protocols, trained observers and physicians, and calibrated equipment for BIA in the standardized environment of the mobile examination center. During the BIA procedure, subjects lay in a supine position on a nonconductive examination table without a pillow under their head. Disposable foil-gum type electrodes were then attached to the right wrist, hand, ankle, and foot after being cleaned with alcohol and gauze. The subject was instructed to remain motionless and relaxed with their arms and legs slightly apart and not touching any other part of the body. Resistance and reactance values (in ohms) were recorded from the BIA unit. All subjects were requested to not eat or drink anything except water during the fasting period. There were no restrictions on physical activity or alcohol consumption before the fasting period. Detailed information on the BIA procedure is presented elsewhere (17, 18).

The %BF estimates were derived from prediction equations for fat-free mass (FFM) that were validated and cross-validated for men and women separately and for blacks and whites between the ages of 12 and 94 y (16). The equations for men and for women are as follows:

\[\text{Men: FFM (kg)} = -10.68 + 0.65 \times S^2/\text{resistance} + 0.26 \times \text{weight} + 0.02 \times \text{resistance} \]

\[\text{Women: FFM (kg)} = -9.53 + 0.69 \times S^2/\text{resistance} + 0.17 \times \text{weight} + 0.02 \times \text{resistance} \]

where \(S^2/\text{resistance}\) is stature squared divided by resistance (cm\(^2\)Ω). We then calculated %BF as follows:

\[\%\text{BF} = 100 \times (\text{weight} - \text{FFM})/\text{weight} \]

Definition of metabolic syndrome

Metabolic syndrome was defined according to ATP III criteria that required the presence of ≥ 3 of the following 5 risk factors (6): abdominal obesity (waist circumference > 102 cm in men and > 88 cm in women), high triacylglycerol concentrations (≥ 1.70 mmol/L, or ≥ 150 mg/dL), low HDL-cholesterol concentrations (< 1.04 mmol/L (40 mg/dL) for men and < 1.30 mmol/L (50 mg/dL) for women), high blood pressure (systolic ≥ 130 mm Hg or diastolic ≥ 85 mm Hg), and high fasting plasma glucose concentrations (≥ 6.11 mmol/L, or ≥ 110 mg/dL). Subjects met the criteria for high blood pressure or high fasting glucose if they were currently using blood pressure or oral hypoglycemic diabetes control medications.

Socioeconomic and lifestyle-related factors

Physical activity level was defined on the basis of the subject’s physical activity intensity rating scores (ie, the ratio of activity metabolic rate to resting metabolic rate) (18) obtained from participating in one of the following activities during the past month: walking, jogging or running, bicycle riding, swimming, lifting weights, aerobic exercise, aerobic or other dancing, calisthenics, or garden or yard work. Subjects in the physically inactive, moderate active, and active categories included those with a total intensity rating score of ≤ 3.5, 3.6–14.9, and ≥ 15, respectively. The point at which the total intensity rating score equals 3.5 and 15 corresponds to approximately the 15th and 25th percentiles and the 65th and 75th percentiles in the men and women, respectively. Education level was divided into 3 categories: < 8, 8–12, and ≥ 12 y. Economic status was divided into 3 categories according to the subject’s household income for the previous year: ≤ $15,000, $15,001–$25,000, and > $25,000. Smoking status was categorized as current smokers, past smokers, and never smokers. Past smokers were those who reported that they had smoked ≥ 100 cigarettes during their lifetime but who did not currently smoke cigarettes.
Drinking was categorized as heavy, moderate, never drank, and unknown. Heavy drinkers were defined as subjects who ever drank ≥5 alcoholic beverages/d or drank beer, wine, or hard liquor 1 time/d during the past month. Moderate drinkers consumed an alcoholic beverage (ie, beer, wine, or hard liquor) less than once per day during the past month. Never drinkers were those who did not drink beer, wine, or hard liquor during the past month. We used the caloric intake from carbohydrate, expressed as a percentage of total kilocalories, as one relevant measure of dietary composition. The percentage of total caloric intake from carbohydrates was categorized as high (>60%), middle (40–60%), or low (<40%). Energy intakes of 40% and 60% from carbohydrate correspond to approximately the 22nd and 86th percentiles in men and the 17th and 81st percentiles in women, respectively. Menopausal status was defined according to self-reported cessation of menstruation at interview. We used dummy variables for these categorized variables in the regression models. The reference group was set as never smokers for smoking, moderate drinkers for alcohol use, a low percentage of energy from carbohydrate intake, physically active for physical activity, >12 y of education for education level, and a household income >$25 000 for income level.

Statistical analyses

Subject characteristics, the percentage of risk factors, and the presence of metabolic syndrome were compared between black and white subjects by sex with the use of the adjusted Wald test. Graphic presentations of %BF distributions according to population percentile and age-specific %BF values in 10-y increments are provided. The %BF in each age and sex group was also compared between black and white subjects with the use of the adjusted Wald test.

Multiple regression analysis was performed to detect the relation between %BF and BMI as continuous variables. In regression models, %BF was the dependent variable and the independent variables were BMI and BMI², or inverse BMI (ie, 1/BMI), respectively. BMI² was tested in regression models to observe whether the relation between %BF and BMI was curvilinear. The coefficients of determination (R²) for each regression model were calculated, and the differences in R² between the model with and without BMI² were also obtained.

Using logistic regression models, we estimated β coefficients for the presence or absence of the metabolic syndrome as a function of %BF or BMI, adjusted for age, smoking, alcohol, physical activity, education level, economic status, dietary habits, and menopausal status. Specifically, the ORs were calculated by comparing odds at one cutoff of %BF or BMI for having the metabolic syndrome with the ORs at a reference point. The equation for calculating OR was as follows:

\[ OR = \exp(\beta(X - X_{\text{ref}})) \] (4)

where \( X \) is a specific %BF or BMI value, cutoff \( X_{\text{ref}} \) is the reference point, and \( \beta \) is the coefficient parameter of %BF and BMI derived from logistic regression models. The reference point was set at the BMI for the 25th percentile in the men and women by race. We then obtained the reference point for %BF that corresponds to BMI values at the 25th percentile through the regression equations of %BF with BMI by sex and race [black men (%BF: 18.8%; BMI: 23.0), black women (%BF: 30.5%; BMI: 23.5), white men (%BF: 19.2%; BMI: 23.7), and white women (%BF: 26.7%; BMI: 21.8)]. These reference values were chosen because the BMI values corresponding to the 25th percentile in the study population are considered to have the lowest risk of death from any cause (19, 20). The prevalence of metabolic syndrome at BMI references (BMI of 23–24 for black and white men and black women and 21–22 for white women) is 3.8% for black men, 5.0% for white men, 7.2% for black women, and 4.1% for white women. Normal values for %BF (thresholds) were identified at which the ORs for %BF corresponded to those seen at BMIs of 18.5, 25, 30, and 35, ie, the cutoffs for normal weight, overweight, obesity I, and obesity II, respectively, as defined by the WHO (2). The significance of interactions of race and age with BMI and %BF in relation to the metabolic syndrome were also tested in logistic regression models.

All analyses incorporated sampling weights to produce nationally representative estimates. We used STATA (version 7.0 for WINDOWS; Stata Corporation, College Station, TX) to calculate weighted means, percentages, ORs, and SEs to adjust for the complex NHANES III sampling design. Statistical significance was set at \( P < 0.05 \).

RESULTS

Descriptive statistics

The race-specific characteristics of men and women at baseline are shown in Table 1. The white men and women were older than the black men and women. There was no significant difference in height, weight, BMI, or %BF between the black and white men. Waist circumference was significantly greater in the white than in the black men. The black women had a significantly greater mean height, weight, waist circumference, BMI, and %BF than did the white women.

The percentage of metabolic syndrome risk factors among men and women by race is also shown in Table 1. There were no statistically significant differences in the prevalence of high blood pressure and high glucose between the black and white men. The percentages of white men with a large waist circumference, a high triacylglycerol concentration, a low HDL concentration, and the metabolic syndrome were significantly greater than those of black men. A higher percentage of black than of white women had a large waist circumference and a high glucose concentration. A higher percentage of white than of black women had a high triacylglycerol concentration. There were no significant race differences in the percentages of women with low HDL concentrations, high blood pressure, and metabolic syndrome.

We developed a series of regression models linking %BF with BMI. All β coefficients for BMI and BMI² in the regression model were significant, which indicated a nonlinear relation between %BF and BMI. Coefficients of determination were \( R² = 0.63 \) and 0.58 for black and white men and 0.87 and 0.85 for black and white women, respectively. The differences in \( R² \) values between models with and without BMI² were <0.03 for men and <0.08 for women. The relation between %BF and BMI when inverse BMI was used as the independent variable in the regression models is shown in Figure 1. Curves for blacks and whites were not significantly different in men or women. Coefficients of determination were almost identical to the regression model with BMI and BMI² \( (R² = 0.63 \) and 0.58 for black and white men and 0.88 and 0.86 for black and white women, respectively).

Percentiles for %BF and BMI distribution are shown in Figure 2, and sex- and race-specific %BF and BMI by age group are shown
in Figure 3. There was no significant difference in %BF or BMI between black and white men at any age group except for the 20–29 y age group. In the 20–29 y age group, black men had a significantly higher %BF or BMI than did white men; %BF reached a peak in the 50–59 y age group in blacks and in the 60–69 y age group in whites. A similar pattern was observed for BMI.

Black women had a significantly higher %BF or BMI than did white women at any age group, except for the ≥80 y age group; %BF increased with age and reached a peak in the 40–49 y age group in blacks and in the 50–59 y age group in whites. A similar pattern was found for BMI.

Logistic regression model

BMI and %BF were tested separately in logistic regression models as main predictor variables and with metabolic syndrome as the dependent variable. These 2 regression models were simultaneously adjusted for age, smoking and drinking status, physical activity, economic and education levels, dietary habits, and menopausal status for women. The β coefficients for BMI and %BF, respectively, were 0.224 and 0.165 with SEs of 0.031 and 0.023 for black men and were 0.132 and 0.130 with SEs of 0.013 and 0.012 for black women and 0.224 and 0.175 with SEs of 0.017 and 0.013 for white men and 24%, 31%, 37%, and 43% for black and white women.

The %BF cutoffs that correspond to similar ORs of BMI are shown in Table 3. The mean %BF cutoffs that show an equivalent risk of having the metabolic syndrome at BMIs of 18.5, 25, 30, and 35, respectively, are 11%, 20%, 28%, and 35% for both black and white men and 24%, 31%, 37%, and 43% for black and white women.

We added BMI or %BF into the regression models to test whether the relation of BMI or %BF with metabolic syndrome was curvilinear. The results showed that all of the relations between BMI and metabolic syndrome for different races or sexes

### Table 1

| Table 1: Subject characteristics and the prevalence of metabolic risk factors |
|-------------------------------|-------------------|-------------------|-------------------|
|                                | Men               | White             | Women             |
| Sample size (n)                | 1211              | 2238              | 1417              |
| US population (millions)       | 5.1               | 47.7              | 6.1               |
| Mean values                    |                   |                   |                   |
| Age (y)                        | 40.3 (39.6, 41.0) | 44.6 (43.7, 45.5) | 41.3 (40.2, 42.3) |
| Height (cm)                    | 176.6 (176.2, 177.1)| 176.6 (176.2, 177.1)| 163.1 (162.7, 163.5)|
| Weight (kg)                    | 83.4 (82.3, 84.4)  | 83.6 (82.5, 84.7)  | 76.7 (75.5, 78.0)  |
| WC (cm)                        | 92.1 (91.2, 93.0)  | 96.6 (95.8, 97.4)  | 92.8 (91.7, 93.8)  |
| BMI (kg/m²)                    | 26.7 (26.4, 27.0)  | 26.7 (26.5, 27.0)  | 28.8 (28.4, 29.2)  |
| %BF (%)                        | 22.4 (21.9, 22.8)  | 22.1 (21.7, 22.5)  | 35.9 (35.4, 36.3)  |
| Prevalence of metabolic risk factors |                   |                   |                   |
| Large WC (%)                   | 21.3 (19.2, 23.5)  | 30.6 (28.7, 32.5)  | 57.9 (55.0, 60.8)  |
| High TG (%)                    | 20.0 (16.6, 23.3)  | 38.0 (34.0, 42.0)  | 13.5 (11.5, 15.4)  |
| Low HDL (%)                    | 22.3 (19.7, 24.8)  | 36.9 (33.6, 40.3)  | 36.4 (34.0, 38.8)  |
| High BP (%)                    | 40.6 (37.4, 43.7)  | 37.4 (34.9, 39.9)  | 30.5 (26.8, 34.2)  |
| High glucose (%)               | 10.8 (8.9, 12.7)   | 10.3 (8.4, 12.2)   | 10.3 (8.7, 11.8)   |
| Metabolic syndrome (%)         | 14.0 (11.2, 16.8)  | 24.6 (21.5, 27.6)  | 20.7 (18.0, 23.4)  |

1 BP, blood pressure; TG, triacylglycerols; WC, waist circumference; %BF, percentage body fat.
2,3 Significantly different from blacks, within sex (adjusted Wald test): 2 P < 0.001, 3 P < 0.01.
4 Defined as ≥102 cm in men and ≥88 cm in women.
5 Defined as < 1.04 mmol/L (40 mg/dL) for men and < 1.30 mmol/L (50 mg/dL) for women.
6 Defined as a fasting serum glucose concentration ≥7.0 mmol/L (126 mg/dL).
7 Defined as a systolic blood pressure ≥130 mm Hg or a diastolic blood pressure ≥85 mm Hg.
8 Defined as a fasting serum glucose concentration ≥11.1 mmol/L (200 mg/dL).
9 Defined as ≥3 of the above 5 risk factors.
FIGURE 2. Percentile distribution of percentage body fat (%BF) and BMI in black men (n = 1211), white men (n = 2238), black women (n = 1417), and white women (n = 2446). Note that the y axis is different in the 2 panels. △, %BF in blacks; ▲, %BF in whites; □, BMI in blacks; ■, BMI in whites.

FIGURE 3. Relation between percentage body fat (%BF) and BMI versus age in black men (n = 1211), white men (n = 2238), black women (n = 1417), and white women (n = 2446). The 95% CI is expressed as the mean ± 2.0 SE. %BF in each age group was compared between black and white subjects within sex by using the adjusted Wald test. Note that the y axis is different in the 2 panels. △, %BF in blacks; ▲, %BF in whites; □, BMI in blacks; ■, BMI in whites.

were curvilinear, whereas the relation between %BF and metabolic syndrome was curvilinear only for black men.

We also added the interaction terms between BMI or %BF and race (white = 1; black = 0) in the logistic regression model to test whether the β coefficients of BMI and %BF in Table 2 were significantly different between white and black subjects. The interaction terms were all positive and were statistically significant for BMI in men and for %BF and BMI in women: men (BMI: β = 0.077, P = 0.014; %BF: β = 0.027, P = 0.219) and women (BMI: β = 0.090, P = 0.001; %BF: β = 0.046, P = 0.019).

We examined whether the relation between %BF and metabolic syndrome differs as a function of age by adding (%BF × age) to the logistic regression model. The interaction term was significant for white men and for white and black women: white men (β = −0.002, P = 0.014), white women (β = 0.001, P = 0.030), black men (β = −0.0008, P = 0.380), and black women (β = −0.001, P = 0.013). However, the relative percentage change in log likelihood of the regression model with the interaction term as opposed to the model without the term was only 0.09–0.4%. In addition, we also calculated the %BF cutoffs for 3 age groups (20–39, 40–59, and ≥60 y) of black and white men and women. In women, %BF cutoffs did not increase with age. At cutoffs equivalent to BMIs of 25 and 30, the differences in %BF cutoffs between the age groups were ~1%. In men, at cutoffs equivalent to a BMI of 25, %BF cutoffs increased slightly (0.5% in whites, 1.2% in blacks) from the 20–39 y age group to the ≥60 y age group. At %BF cutoffs equivalent to a BMI of 30, %BF cutoffs increased by 3% in whites and by 5% in blacks from the 20–39 y age group to the ≥60 y age group.

DISCUSSION

We developed OR prediction models for the presence of metabolic syndrome based on %BF with the use of a nationally representative sample. We then used these models to calculate %BF...
cutoffs for metabolic syndrome that provide a risk equivalent to that of well-established BMI thresholds recognized by the NIH and WHO (1, 2). These cutoffs for %BF and the associated ranges for normal-weight, overweight, and obesity categories vary by sex but are largely independent of age and race (ie, black and white).

Accordingly, a simplified set of suggested ranges for %BF as they relate to the metabolic syndrome are presented in Table 3.

Gallagher et al (14) suggested normative values for %BF linked directly to BMI, but to our knowledge the present study reports the first attempt to provide BMI ranges associated with the metabolic syndrome. The developed ranges match the BMI-related risk of metabolic syndrome presence at the 4 thresholds. We aligned the %BF ranges with BMI because the BMI ranges are now accepted by consensus in the United States and Europe. An alternative, ie, the calculation of %BF ranges directly associated with the metabolic syndrome risk, is possible with the use of the OR models, although the developed ranges would bear no relation to the current BMI framework now embraced in the clinical setting. The specific odds of metabolic syndrome presence can be estimated for men and women at any given %BF value by using the equations in Table 2.

Although obesity is associated with many adverse health conditions and outcomes (8–14), we selected metabolic syndrome in this analysis because it is a common disorder encompassing several related biological measures (4–7), has a formal definition (6), and is linked with 2 important weight-related comorbidities: diabetes and cardiovascular disease (1, 3, 14, 21). A similar approach could be applied in developing ranges for other weight-related health conditions and biomarkers, such as high blood pressure, glucose tolerance, and serum lipid concentrations.

Our analysis, based on the representative NHANES III database, indicates the complexities of preparing normative population ranges. Several important considerations arose in the process of developing the proposed ranges, and we review these in additional detail below.

**Percentage body fat estimated by bioelectrical impedance analysis**

BMI is usually considered to be a surrogate marker of excess adiposity when considering the health risks of overweight and obesity (8–14). A desirable alternative is to use actual measures of fatness rather than of body mass (14). NHANES III included 2 measures of body fatness other than BMI, anthropometric measurements and BIA. Most researchers consider BIA to be a more accurate method for estimating %BF than are anthropometric measurements (8–13), particularly when BIA measurements are made under carefully controlled conditions (9, 17, 22). BIA prediction formulas based on resistance, reactance, and other variables are often population specific and are developed with small sample sizes limited in the range of evaluated ages, weights, and ethnicities. Our study was made possible by the recent introduction of prediction formulas based on BIA-measured %BF that were validated for use in white and black subjects representing a broad range of ages and BMIs from 5 US study sites (16). Although BIA may provide reasonable group %BF values, our results should be considered provisional while we await confirmation with the use of dual-energy X-ray absorptiometry in NHANES IV. Our approach, regardless of the method used to estimate %BF, should be generalizable to other measurement methods and clinical conditions.

We observed a curvilinear relation between %BF and BMI. However, we used inverse BMI (1/BMI) to develop the BMI-%BF relation model rather than BMI and BMI\(^2\), because when BMI becomes extremely large, the curve of BMI with %BF begins to decrease as a result of the quadratic term. A decrease in %BF with increasing BMI seems highly unlikely. Gallagher et al (14) also

### TABLE 2

<table>
<thead>
<tr>
<th>BMI (kg/m(^2))</th>
<th>%BF (%)</th>
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<tbody>
<tr>
<td><strong>Men</strong></td>
<td><strong>Episode</strong></td>
</tr>
<tr>
<td><strong>Black</strong></td>
<td><strong>White</strong></td>
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<tr>
<td><strong>Women</strong></td>
<td><strong>White</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equation</th>
<th>(\beta) coefficient</th>
<th>SE of (\beta) coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>(OR_{BMI} = \exp[0.224(BMI - 23.0)])</td>
<td>0.224</td>
<td>0.031</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.234(BMI - 23.7)])</td>
<td>0.305</td>
<td>0.023</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.132(BMI - 23.5)])</td>
<td>0.132</td>
<td>0.013</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.224(BMI - 21.8)])</td>
<td>0.224</td>
<td>0.017</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.165(%BF - 18.8)])</td>
<td>0.165</td>
<td>0.016</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.194(%BF - 19.2)])</td>
<td>0.194</td>
<td>0.012</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.130(%BF - 30.5)])</td>
<td>0.130</td>
<td>0.012</td>
</tr>
<tr>
<td>(OR_{BMI} = \exp[0.175(%BF - 26.7)])</td>
<td>0.175</td>
<td>0.013</td>
</tr>
</tbody>
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1. OR\(_{BMI}\) odds ratio for metabolic syndrome for BMI; OR\(_{%BF}\) odds ratio for metabolic syndrome for percentage body fat; Exp, exponent; %BF, percentage body fat.
observed a curvilinear relation between BMI and %BF estimated with DXA, and these investigators developed their %BF prediction formulas with 1/BMI as a predictor variable rather than BMI or BMI^2. In fact, the coefficients of determination for the regression modeled by BMI and BMI^2 and the regression modeled by inverse BMI were almost identical, which implies that the use of inverse BMI as a predictor in relation to %BF may be preferable.

Cross-sectional NHANES sample

The NHANES III database is cross-sectional, which limits interpretation of our OR metabolic syndrome models. The OR predictions of the presence of metabolic syndrome should apply to subjects in the United States at any given point in time. However, there may be cohort effects across age strata; thus, if and to what extent our metabolic syndrome risk prediction models are accurate within an individual person followed over time remains uncertain. To some extent, similar interpretation constraints apply to BMI ranges produced from cross-sectional samples such as NHANES III. Ultimately, longitudinal data are needed to establish whether our prediction models accurately characterize the long-term risk of developing the metabolic syndrome.

Relation between percentage body fat and age

Many cross-sectional and longitudinal studies indicate that %BF in adults increases with age in both men and women (14, 23, 24). On closer examination, %BF in the population as a whole appears to increase with age up to middle age and then to decreases later in life (8, 25, 26). This curvilinear trend shows a pattern similar to the age-specific prevalence of the metabolic syndrome as well as fat mass defined by BMI in the US population (7, 27). Because our suggested %BF ranges may be influenced by the interaction between age and %BF, we examined these associations in detail. Our results show that the effects of %BF on the risk of metabolic syndrome may depend on age, but the magnitude of this effect is very small, which suggests that the %BF ranges may be generalizable for all US blacks and whites aged ≥20 y. The BIA equations used in this study were derived by using a multicomponent model (28) to generate body-composition estimates, and this modeling strategy largely eliminates any potential age bias in the measurement of reference values for %BF (16).

Given the collective concerns related to the reference body-composition method, cross-sectional sample, and related age-%BF interactions, our suggestion is to limit the use of the developed OR equations to the population as a whole rather than to predict an individual person’s odds of having metabolic syndrome on the basis of %BF.

Relation between percentage body fat and sex and race

The women in our study had higher %BF values than did the men, and their developed %BF cutoffs for metabolic syndrome risk were also higher. Many earlier studies report a higher body fat in women than in men of comparable BMI, which suggests the necessity of using a sex-specific %BF range for predicting the risk of the metabolic syndrome (29, 30). The relation between %BF and BMI was not significantly different between blacks and whites in the current study (Figure 1). Black women had the highest overall %BF of the 4 race and sex groups evaluated. In addition, the rate of increase in the risk of metabolic syndrome with increasing BMI and %BF was greater in blacks than in whites. As defined by ATP III, Park et al (7) also noted a lower OR for metabolic syndrome in US blacks than in US whites after adjustment for BMI, age, socioeconomic status, physical activity level, and other predictor variables (7). The reason for this is unclear, particularly because blacks have a high risk of cardiovascular disease and diabetes; however, at the same waist circumference, blacks have relatively smaller depots of insulin-resistance-related visceral adipose tissue than do whites (31–35). Our %BF ranges, linked with the risk of metabolic syndrome based on BMI, were similar across race groups for men and women because the ORs derived from regression models were based on a comparison with the ORs for metabolic syndrome in subjects at the 25th percentile of a race-specific population.

Conclusions

This study reports %BF thresholds that correspond to the risk of metabolic syndrome based on traditional BMI cutoffs, as established by the NIH and WHO, and provides equations for estimating the risk (OR) of metabolic syndrome for any given %BF, sex, and race. The developed OR models and associated cutoffs can be used as provisional guidelines for recommending ranges of %BF that indicate a minimal risk of developing the metabolic syndrome.

SZ designed the study and analyzed the data. SZ and SBH wrote the manuscript. SBH, SH, ZW, and WS provided advice. SH and SH provided administrative support and supervision. None of the authors had a financial or personal interest in any company or organization sponsoring this study.

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