

# Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index<sup>1-3</sup>

Dympna Gallagher, Steven B Heymsfield, Moonseong Heo, Susan A Jebb, Peter R Murgatroyd, and Yoichi Sakamoto

## ABSTRACT

**Background:** Although international interest in classifying subject health status according to adiposity is increasing, no accepted published ranges of percentage body fat currently exist. Empirically identified limits, population percentiles, and *z* scores have all been suggested as means of setting percentage body fat guidelines, although each has major limitations.

**Objective:** The aim of this study was to examine a potential new approach for developing percentage body fat ranges. The approach taken was to link healthy body mass index (BMI; in kg/m<sup>2</sup>) guidelines established by the National Institutes of Health and the World Health Organization with predicted percentage body fat.

**Design:** Body fat was measured in subjects from 3 ethnic groups (white, African American, and Asian) who were screened and evaluated at 3 universities [Cambridge (United Kingdom), Columbia (United States), and Jikei (Japan)] with use of reference body-composition methods [4-compartment model (4C) at 2 laboratories and dual-energy X-ray absorptiometry (DXA) at all 3 laboratories]. Percentage body fat prediction equations were developed based on BMI and other independent variables.

**Results:** A convenient sample of 1626 adults with BMIs  $\leq 35$  was evaluated. Independent percentage body fat predictor variables in multiple regression models included 1/BMI, sex, age, and ethnic group (*R* values from 0.74 to 0.92 and SEEs from 2.8 to 5.4% fat). The prediction formulas were then used to prepare provisional healthy percentage body fat ranges based on published BMI limits for underweight ( $< 18.5$ ), overweight ( $\geq 25$ ), and obesity ( $\geq 30$ ).

**Conclusion:** This proposed approach and initial findings provide the groundwork and stimulus for establishing international healthy body fat ranges. *Am J Clin Nutr* 2000;72:694–701.

**KEY WORDS** Obesity, percentage body fat, malnutrition, nutritional assessment, body fat guidelines, body composition, prediction equations

## INTRODUCTION

With worldwide rates of obesity increasing steadily, the National Institutes of Health (NIH) and the World Health Organization (WHO) recently adopted similar body weight guidelines for overweight and obesity (1, 2). Values of body weight adjusted for height, referred to as body mass index (BMI; in kg/m<sup>2</sup>), in excess of 25 and 30 are considered to indicate overweight and obesity,

respectively. A lower healthy BMI limit of 18.5 was also identified by both organizations (1, 2). These body weight guidelines are useful for practitioners when screening patients for excessive adiposity and when prescribing treatment for overweight patients.

The main assumption of BMI guidelines is that body mass, adjusted for stature squared, is closely associated with body fatness and consequent morbidity and mortality (3, 4). However, some individuals who are overweight are not overfat (eg, body-builders). Others have BMIs within the normal range and yet have a high percentage of their body weight as fat. Although these misclassified persons are uncommon relative to the population as a whole (1), the question arises as to how they might be evaluated correctly according to body fatness. Moreover, screening and retention of military recruits (5, 6), policemen, firemen (7), and other workers in whom high fitness levels are required are often based on BMI standards and in some cases on a second-tier body fat evaluation (5).

Unfortunately, there is no consensus on how body fat is linked with morbidity and mortality because of the absence of appropriate prospective studies. Specifically, no accepted published body fat ranges exist; those reported based on empirically set limits, population percentiles, and *z* scores have serious limitations. Additionally, methods of limited accuracy such as anthropometry are typically used to estimate fatness in population surveys (8).

The aim of the present study was to examine an approach for developing percentage body fat ranges that correspond to published BMI guidelines. Sex-specific formulas were first developed for estimating relative body fatness from BMI and other potential independent variables such as age and ethnicity. These formulas, based on reference methods for evaluating total body fat, were then used to derive percentage body fat levels corresponding to the BMI thresholds for underweight ( $< 18.5$ ), overweight ( $\geq 25$ ), and obesity ( $\geq 30$ ).

<sup>1</sup>From the Obesity Research Center, St Luke's-Roosevelt Hospital, Columbia University College of Physicians and Surgeons, New York; MRC Human Nutrition Research, Cambridge, United Kingdom; and Kashiwa Hospital, Jikei University, Chiba, Japan.

<sup>2</sup>Presented in part at the 1999 European Congress on Obesity, Milan, Italy.

<sup>3</sup>Address reprint requests to SB Heymsfield, Weight Control Unit, 1090 Amsterdam Avenue, 14th Floor, New York, NY 10025. E-mail: sbh2@columbia.edu.

Received August 5, 1999.

Accepted for publication January 24, 2000.

## SUBJECTS AND METHODS

### Subjects

Subjects were a convenient sample recruited through advertisements in local newspapers, through posted flyers, or through referral for body weight evaluation. After passing the screening evaluation, subjects completed dual-energy X-ray absorptiometry (DXA), labeled water dilution, and underwater weighing studies on the same day.

Adult subjects with BMIs  $\leq 35$  were evaluated. Subjects were excluded if they had a history of recent acute illness (eg, pneumonia or myocardial infarction), had a chronic condition (eg, cancer, uncontrolled high blood pressure, or collagen vascular disease), or were actively engaged in a vigorous ( $> 6$  h/wk) physical activity training program.

Subjects were screened through a medical history questionnaire, physical examination, and measurement of routine blood chemistry indexes. Healthy subjects were enrolled in the study and completed up to 5 evaluations: weight, height, DXA for body fat and bone mineral mass, tritium or deuterium dilution for total body water, and hydrostatic weighing for body density and volume. The measured bone mineral mass, total body water, and body volume values were then used to calculate total body fat by using a 4-compartment model (4C) (9). The study was performed in accord with the Helsinki Declaration of 1975 as revised in 1983.

### Experimental design

Three groups of subjects (white, African American, and Asian) were evaluated at MRC Nutrition Research (United Kingdom), Columbia University (United States), and Jikei University (Japan). White subjects were evaluated at both the UK and US sites whereas African American subjects were evaluated at the US site only and all Asians were Japanese evaluated at the Japan site. Body fat was measured by DXA at all 3 centers and, additionally, tritium or deuterium dilution volume, bone mineral mass, and body density were measured at the UK and US sites. Two measures of percentage body fat were used at the UK and US sites, DXA and 4C, whereas DXA alone was used at the Japan site.

### Body composition

DXA scanners were used to measure body composition [Japan: DPX-L with software version 1.3z (Lunar Radiation Corp, Madison, WI); United Kingdom: QDR 1000 with enhanced software (Hologic Inc, Bedford, MA); and United States: DPX with software version 3.6 (Lunar Radiation Corp)]. These had CVs of  $\approx 1.5\%$  for bone mineral (10) and 3–4% for body fat (11).

Tritium space ( $^3\text{H}_2\text{O}$ , in L) was measured at the US site with a CV of 1.5% (12). Deuterium space ( $\text{D}_2\text{O}$ ) was evaluated at the UK site by using infrared spectroscopy with a CV of  $< 1\%$  (13). The tritium and deuterium spaces were then converted into total body water (in kg) with a correction factor for nonaqueous hydrogen exchange and water density at  $36^\circ\text{C}$  (total body water =  $^3\text{H}_2\text{O}$  or  $\text{D}_2\text{O} \times 0.96 \times 0.994$ ) (14).

Body density and volume were measured by underwater weighing in water tanks according to standard methods with a technical error of  $0.0020 \text{ g/cm}^3$  (15). Residual lung volume was estimated after immersion of subjects in a sitting position by means of the closed-circuit oxygen dilution method in the United States (16) and at the time of immersion by helium dilution in the United Kingdom (9, 17).

**TABLE 1**

Subject sample size by site, sex, and ethnicity

Sex and ethnicity	Site			Total
	United States	Japan	United Kingdom	
Women				
African American	155	0	0	155
Asian	0	633	0	633
White	127	0	98	225
Subtotal	282	633	98	1013
Men				
African American	99	0	0	99
Asian	0	322	0	322
White	94	0	98	192
Subtotal	193	322	98	613
Total	475	955	196	1626

### Statistical analysis

Body fat estimates made with the 4C method were available from the UK and US sites. The 4C method is generally accepted as a reference method for measuring body fat (17, 18). Body fat estimates by DXA, a second reference method (17, 18), were also available from all 3 sites. The same DXA systems and software were used at the US and Japan sites, facilitating conversion of percentage body fat by DXA in Japanese subjects to a corresponding 4C percentage body fat value. Specifically, the DXA-4C conversion was carried out by using simple regression analysis with 4C percentage body fat as the dependent variable and DXA percentage body fat as the independent variable with use of data collected at the US site. The DXA-4C conversion was intended solely to make Japanese DXA percentage body fat estimates consistent in magnitude with 4C percentage body fat estimates from the UK and US sites. We were therefore able to create, for exploratory purposes, 2 complete sets of operational percentage body fat formulas based on BMI and other potential independent variables: one with DXA percentage body fat as the dependent variable and the other with 4C percentage body fat as the dependent variable.

Models for predicting percentage body fat were developed by using multiple regression analysis with 1/BMI, age, sex, and ethnicity evaluated as potential independent variables. The 1/BMI term was used to linearize the data and to avoid the need for logarithmic conversion or inclusion of power terms (19, 20). Potential interaction terms were explored in model development and a forward-backward stepwise selection procedure was applied for the derivation of prediction equation models. Group data are presented as means  $\pm$  SDs. All analyses were carried out with the statistical software program SPSS (version 8.0, 1998; SPSS Inc, Chicago).

## RESULTS

### Subjects

The subject sample size by site, sex, and ethnicity is summarized in **Table 1**. The total subject pool consisted of 1626 subjects, 1013 women and 613 men. The subject pool included 254 African Americans, 955 Asians, and 417 whites.

Subject demographic characteristics by sex and ethnicity are summarized in **Table 2**. Mean age varied from 39.3 y in Asian women to 56.2 y in African American women. African American women had the highest mean weight (71.5 kg) among the

TABLE 2  
Demographic characteristics of subjects<sup>1</sup>

	Men			Women		
	African American	Asian	White	African American	Asian	White
Age (y)	51.4 ± 17.6	46.7 ± 15.4	48.1 ± 19.2	56.2 ± 16.8	39.3 ± 15.9	48.8 ± 17.6
Weight (kg)	80.2 ± 12.8	64.1 ± 8.9	80.2 ± 11.0	71.5 ± 12.5	56.6 ± 9.7	62.7 ± 10.4
Height (m)	1.75 ± 0.07	1.67 ± 0.06	1.76 ± 0.08	1.62 ± 0.07	1.56 ± 0.06	1.63 ± 0.07
BMI (kg/m <sup>2</sup> )	26.2 ± 3.3	23.1 ± 3.0	25.5 ± 3.8	27.1 ± 4.3	23.2 ± 3.9	24.5 ± 4.5

<sup>1</sup> $\bar{x} \pm SD$ . Sample sizes are presented in Table 1.

women and both male and female Asians had the lowest mean weights within their sex groups. Similarly, Asians were shorter than their white and African American counterparts. BMI was lowest in Asian men and women and highest in African American women (**Figure 1**).

Model considerations

There was a curvilinear relation between percentage body fat and BMI within all groups. An example is presented in the left-hand portion of **Figure 2** for DXA percentage body fat versus BMI in all women. This relation became linear when BMI was replaced by 1/BMI, as shown in the right-hand portion of **Figure 2**. Although logarithmic transformations and various power terms improved the linearity of and correlation coefficients for the relation between percentage body fat and BMI, we chose for simplicity to use 1/BMI instead as an independent variable in all percentage body fat prediction models developed. Additionally, regression models with 1/BMI provided higher *R*<sup>2</sup> and SEE values than did those with BMI or transformations of BMI as independent variables.

There were highly significant correlations between DXA percentage body fat and 4C percentage body fat for men and women at both the UK and US sites. The pooled UK and US DXA and 4C percentage body fat data are plotted in **Figure 3**. The slope and intercept of this relation differed significantly from 1.0 and 0 (both *P* < 0.001), respectively. The bias between the 2 methods was rel-

atively small. For example, when 4C body fat was 10%, 30%, and 50%, DXA body fat was 8.9%, 30.1%, and 51.3%, respectively.

Dual-energy X-ray absorptiometry models

The relations between DXA percentage body fat and 1/BMI for men and women at each of the 3 sites are presented in **Figure 4**. The univariate correlations for DXA percentage body fat versus 1/BMI ranged from *R* = 0.68 to *R* = 0.89 (all *P* < 0.001).

The next phase of analysis involved the addition of other potential independent variables and interaction terms to the developed multiple regression models. The analysis produced the following equation derived by stepwise regression analysis:

$$\begin{aligned} \text{Percentage body fat} = & 76.0 - 1097.8 \times (1/\text{BMI}) - 20.6 \\ & \times \text{sex} + 0.053 \times \text{age} + 95.0 \\ & \times \text{Asian} \times (1/\text{BMI}) - 0.044 \\ & \times \text{Asian} \times \text{age} + 154 \times \text{sex} \\ & \times (1/\text{BMI}) + 0.034 \times \text{sex} \times \text{age} \quad (I) \end{aligned}$$

where multiple *R* = 0.90 and SEE = 4.31% body fat, sex = 1 for male and 0 for female, and Asian = 1 for Asians and 0 for the other races. The model predicted higher percentage body fat in men and in older subjects. The model did not show a significant difference between African Americans and whites for either sex. Asians, however, according to the model, had a significantly higher percentage body fat for any given BMI than did the other 2 ethnic groups.

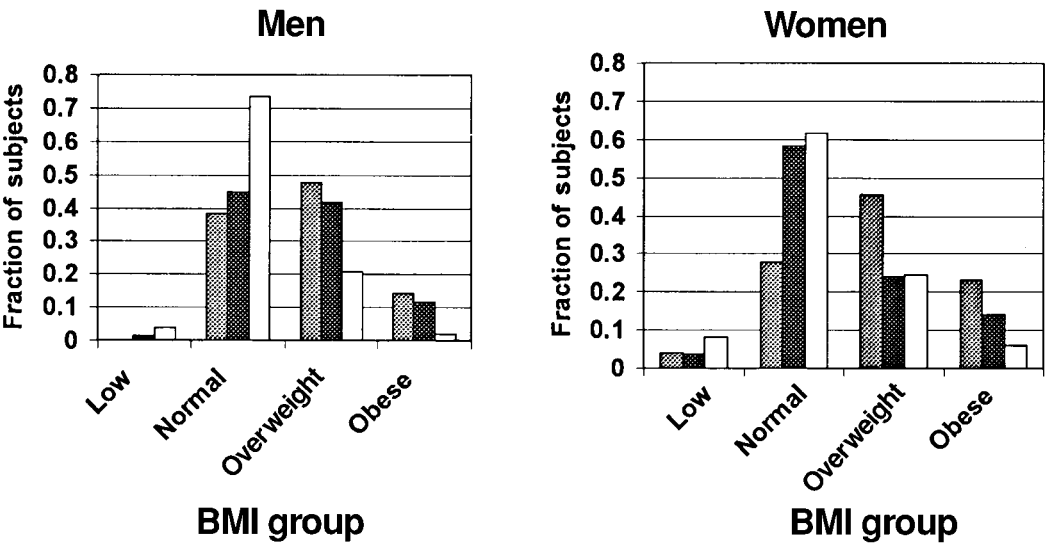
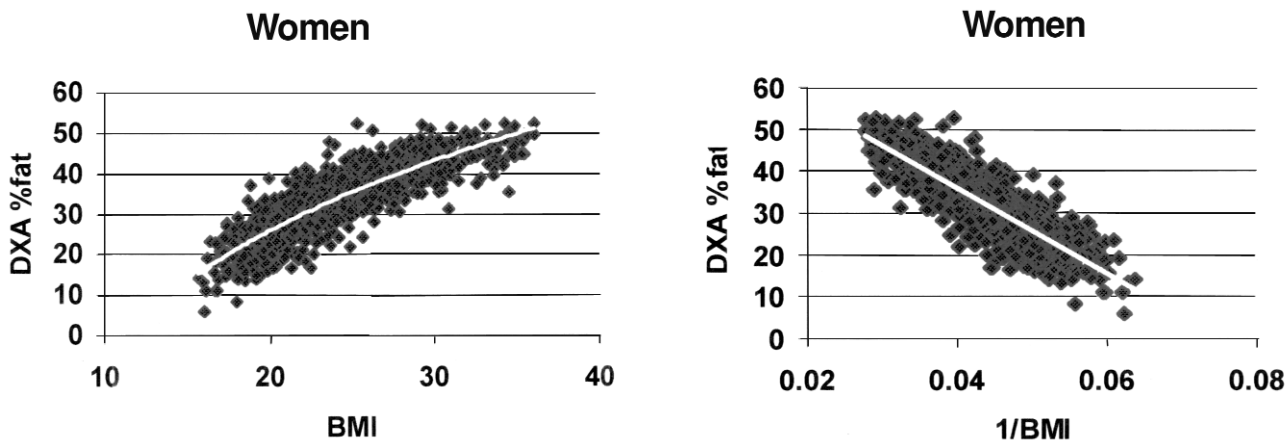


FIGURE 1. Distribution of men and women in the 4 BMI categories. Results are expressed for each ethnic group as a fraction of the total number of subjects in that ethnic and sex group. ■, African American; ■, white; □, Asian.



**FIGURE 2.** Percentage body fat as measured by dual-energy X-ray absorptiometry (DXA %fat) versus BMI and 1/BMI in women. Body fat was a curvilinear function of BMI (left); this relation was linearized by converting BMI to 1/BMI (right). Left:  $y = 42.9 \ln(x) - 102.7$ ;  $R^2 = 0.76$ . Right:  $y = -1023(x) + 76.9$ ;  $R^2 = 0.76$ . All  $P < 0.001$ .

Separate analyses for DXA percentage body fat with use of 1/BMI and age by sex and ethnicity were also carried out, yielding multiple correlations (ie,  $R$  values) ranging from 0.74 to 0.88 and SEEs from 3.8% to 5.4% body fat. These models provided results similar to those for Equation 1 and are not reported herein. Solutions for DXA equations at the 3 BMI levels are not presented because these can be calculated directly from Equation 1. The patterns of estimated percentage body fat ranges are similar to those presented below for the 4C method.

#### Four-compartment models

We calculated a 4C percentage body fat value for each Asian subject by using the following equation to convert DXA to 4C percentage body fat, which was derived by simple regression of 4C percentage body fat on DXA percentage body fat from measurements taken at the US site:

$$\text{Women: 4C percentage body fat} = 7.490 + 0.773 \times \text{DXA percentage body fat} \quad (2)$$

where multiple  $R = 0.92$  and  $\text{SEE} = 3.08\%$  fat, and

$$\text{Men: 4C percentage body fat} = 2.473 + 0.893 \times \text{DXA percentage body fat} \quad (3)$$

where multiple  $R = 0.92$  and  $\text{SEE} = 2.79\%$  fat.

The forward-backward stepwise selection produced the following equation for the 4C percentage body fat estimates:

$$\begin{aligned} \text{Percentage body fat} = & 63.7 - 864 \times (1/\text{BMI}) - 12.1 \times \text{sex} \\ & + 0.12 \times \text{age} + 129 \times \text{Asian} \\ & \times (1/\text{BMI}) - 0.091 \times \text{Asian} \\ & \times \text{age} - 0.030 \times \text{African American} \\ & \times \text{age} \end{aligned} \quad (4)$$

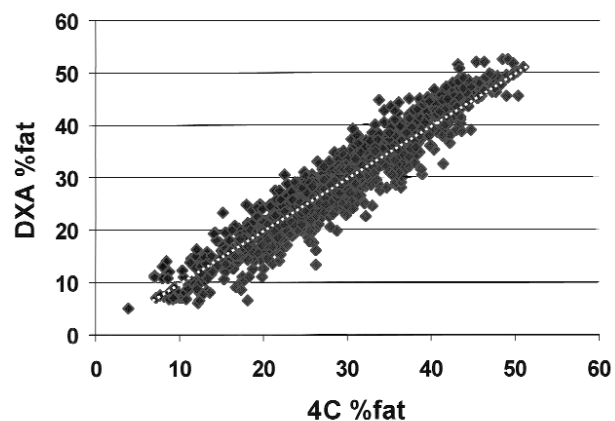
where multiple  $R = 0.89$  and  $\text{SEE} = 3.97\%$  fat, sex = 1 for male and 0 for female, Asian = 1 for Asians and 0 for the other races, and African American = 1 for African Americans and 0 for the other races.

The corresponding 4C percentage body fat ranges are presented in Table 3. According to this model, Asians had higher percentages of body fat at lower BMIs, particularly at younger ages, than did the other 2 ethnic groups. These developed

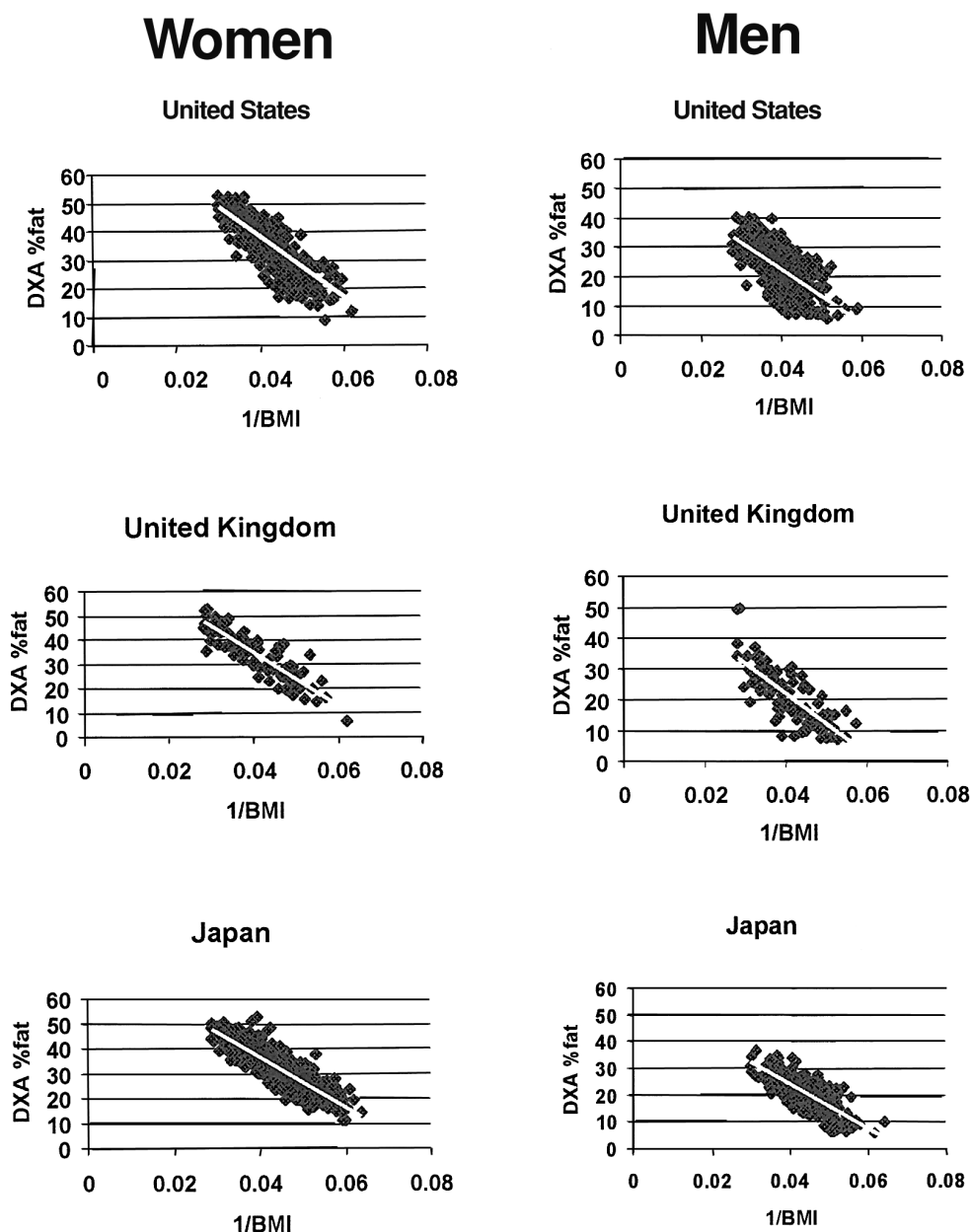
ranges also indicate a small difference between African Americans and whites for males and females, with African American subjects having lower percentages of body fat, particularly at older ages. The difference between African Americans and whites remained significant even when the analysis was repeated for the US data alone.

Although percentage body fat for BMI differed significantly between whites and African Americans (Equation 4), the magnitude of this effect was rather small ( $\approx 1$ –2% fat). For practical purposes, we therefore developed another set of simplified equations by combining the data from white and African American subjects for 4C percentage body fat, as follows:

$$\begin{aligned} \text{Percentage body fat} = & 64.5 - 848 \times (1/\text{BMI}) + 0.079 \times \text{age} \\ & - 16.4 \times \text{sex} + 0.05 \times \text{sex} \times \text{age} \\ & + 39.0 \times \text{sex} \times (1/\text{BMI}) \end{aligned} \quad (5)$$



**FIGURE 3.** Percentage body fat as measured by dual-energy X-ray absorptiometry (DXA %fat) versus 4-compartment estimate of percentage body fat (4C %fat) for all subjects at the UK and US sites. The line of identity is shown in the figure. There was a high correlation between the 2 estimation methods ( $R = 0.95$ ;  $\text{DXA \%fat} = -1.7 + 1.06 \times 4\text{C \%fat}$ ;  $\text{SEE} = 3.2$ ;  $P < 0.001$ ).



**FIGURE 4.** Percentage body fat as measured by dual-energy X-ray absorptiometry (DXA %fat) versus 1/BMI by sex for each of the study sites. The regression lines are shown in the figures. Linear relations were observed between percentage body fat and 1/BMI in both women and men at all 3 study sites, with univariate correlations ranging from  $R = 0.68$  to  $R = 0.89$  (all  $P < 0.001$ ).

where multiple  $R = 0.86$  and  $SEE = 4.98\%$  fat and sex = 1 for male and 0 for female. The resulting estimated 4C percentage body fat ranges by sex and age are presented in **Table 4** and the presented values consolidate the 4C studies in African American and white subjects into a single chart.

In contrast, models for Asians predicted a different percentage body fat from that predicted for African Americans and whites. Therefore, we derived the following 4C equations by sex for Asian subjects only:

$$\text{Asian women: Percentage body fat} = 64.8 - 752 \times (1/\text{BMI}) + 0.016 \times \text{age} \quad (6)$$

where  $n = 322$ , multiple  $R = 0.88$ , and  $SEE = 2.91\%$  fat.

$$\text{Asian men: Percentage body fat} = 51.9 - 740 \times (1/\text{BMI}) + 0.029 \times \text{age} \quad (7)$$

where  $n = 633$ , multiple  $R = 0.77$ , and  $SEE = 3.49\%$  fat. The resulting estimated 4C percentage body fat ranges, converted from those derived by DXA, are presented by sex and age in **Table 5**; these values differ slightly from the Asian values summarized in Table 3.

Separate analyses for 4C percentage body fat with use of 1/BMI and age by sex and ethnicity were also carried out, yielding multiple correlations ranging from 0.74 to 0.88 and SEEs ranging from 2.9% to 5.2% fat. Solutions for equations at the 3 BMI cutoffs are not presented here. However, the patterns of

**TABLE 3**Predicted percentage body fat by sex and ethnicity based on 4-compartment estimates of percentage body fat<sup>1</sup>

Age and BMI	Women			Men		
	African American	Asian	White	African American	Asian	White
	%					
20–39 y						
BMI < 18.5	20	25	21	8	13	8
BMI ≥ 25	32	35	33	20	23	21
BMI ≥ 30	38	40	39	26	28	26
40–59 y						
BMI < 18.5	21	25	23	9	13	11
BMI ≥ 25	34	36	35	22	24	23
BMI ≥ 30	39	41	41	27	29	29
60–79 y						
BMI < 18.5	23	26	25	11	14	13
BMI ≥ 25	35	36	38	23	24	25
BMI ≥ 30	41	41	43	29	29	31

<sup>1</sup>Calculated from Equation 4 centering on the ages of 30, 50, and 70 y.

estimated 4C percentage body fat ranges by these separate equations were similar to those in Table 3.

## DISCUSSION

The information needed to directly associate percentage body fat with morbidity and mortality is, unfortunately, presently unavailable even though there is increasing interest in ranges of body fat associated with optimum health. An alternative approach taken in the present study was to link percentage body fat in adults with current healthy weight guidelines (1, 2). Our analysis extended to 3 populations and used 2 different approaches for measuring body fat. The focus of this study was not to establish definitive body fat ranges, but rather to explore the means and methods by which such guidelines can be created and to stimulate further interest in such models.

## Model development

### BMI transformation

As shown in this study and others (19, 20), the function percentage fat versus BMI is curvilinear and the best fit is often accomplished by using power functions or logarithmic conversions, adding complexity to developed formulas. In creating our prediction models for percentage body fat, we applied the inverse of BMI, 1/BMI, as the main predictor variable. This approach improved the linearity of the association between percentage body fat and BMI and simplified model development. Our observations combined with that of earlier investigations (20) suggest a utility in prediction model development for 1/BMI when subject populations include a wide range of body fatness values.

### Population specificity

The prediction models developed for percentage body fat had significant age and ethnicity terms as independent variables. This highlights a critical concern regarding population specificity with these and similar empirical prediction models. Our population included adults aged ≤ 97 y. All of our developed models indicate that, after 1/BMI is first controlled for, greater age is associated with a higher percentage body fat. Many cross-sectional and longitudinal studies now indicate that relative fatness in adults

increases with age (21–31). Although the mechanisms leading to increasing fatness with age are not fully understood, our findings and those of others suggest that sex, ethnic, and individual differences exist in the rate at which percentage body fat changes with senescence (25, 30, 31). Some of our cross-sectional prediction models for percentage body fat had significant age-by-sex interaction terms (eg, Equation 1), usually in the direction of a greater relative increase in percentage fat with older age in men than in women. An important and as yet unanswered question is whether the greater fatness with older age, even after BMI is first controlled for, poses additional health risks. This important question, highlighted by the present investigation, needs to be examined in future mechanistic and clinical studies.

In addition to an age effect on BMI-predicted percentage body fat, we observed an independent effect of ethnicity or study site. Others made similar observations when studying various ethnic groups at the same or different evaluation sites (32–36). For example, Deurenberg et al (35) found that American blacks had a 1.3-unit lower and Polynesians a 4.5-unit higher BMI than whites with the same body fatness (35). Even within the white cohort, the investigators observed small differences between Americans and Europeans.

The underlying causes of ethnic variation in relations between BMI and percentage body fat are likely due to small

**TABLE 4**Predicted percentage body fat by sex based on 4-compartment estimates of percentage body fat for African Americans and whites<sup>1</sup>

Sex and BMI	20–39 y	40–59 y	60–79 y
	%		
Women			
BMI < 18.5	21	23	24
BMI ≥ 25	33	34	36
BMI ≥ 30	39	40	42
Men			
BMI < 18.5	8	11	13
BMI ≥ 25	20	22	25
BMI ≥ 30	25	28	30

<sup>1</sup>Calculated from Equation 5 centering on the ages of 30, 50, and 70 y.

**TABLE 5**  
Predicted percentage body fat by sex based on 4-compartment estimates of percentage body fat for Asians<sup>1</sup>

Sex and BMI	20–39 y	40–59 y	60–79 y
	%		
Women			
BMI < 18.5	25	25	25
BMI ≥ 25	35	35	36
BMI ≥ 30	40	41	41
Men			
BMI < 18.5	13	13	14
BMI ≥ 25	23	24	24
BMI ≥ 30	28	29	29

<sup>1</sup>Calculated from Equations 6 and 7 centering on the ages of 30, 50, and 70 y.

between-center body fat measurement differences and biological between-group differences (35). The evaluation of Asians was confined to Japan and that of African Americans to the United States. Therefore, the underlying causes of observed ethnic differences in terms of measurement, environmental, and genetic factors are difficult to ascertain. Nevertheless, it appears evident that a single set of universal percentage body fat ranges cannot be easily developed without considerable additional analysis of this problem. Our equations and associated tables provide several ethnic-specific ranges as working guidelines. Because African Americans and whites differed only slightly in percentage body fat (by 1–2%) after BMI was first controlled for, we presented a combined equation (Equation 5) and table (Table 4) based on 4C percentage body fat for these 2 groups.

*Methodologic differences*

An important issue highlighted by the present study is between-method and instrument differences in body fat measurement. Although the various DXA and 4C models we developed provided similar body fat ranges, some notable differences were found (eg, significant African American term in 4C Equation 4 and no comparable term in DXA Equation 1). Moreover, as might be expected between any 2 measurement methods, there was a small but statistically significant bias for DXA versus 4C percentage body fat. Ideally, the identical calibrated measurement system would have been used at all 3 sites for body fat measurement. This optimum situation was not possible in the present study and it is likely that any large-scale international study would face similar methodologic issues.

**Study limitations**

Our subjects, by necessity, were a convenient sample and may not be representative of the populations from which they were recruited. We excluded subjects with recent weight change, those who had acute or chronic illnesses, and those engaged in physical training programs. Moreover, the aim of this study was not to provide population ranges for body fatness as might be a goal of epidemiologic studies. Ideally, however, future prospective studies should consider optimum sampling strategies when prediction formulas for percentage body fat are developed based on BMI.

A second concern involves subjects at or below the lower BMI limit of 18.5. Males with BMIs < 18.5 who are otherwise healthy are relatively uncommon in industrialized nations. Only 2.6% of our male subjects and 6.0% of our female subjects had a BMI

< 18.5 (Figure 1). Hence, our lower BMI percentage body fat ranges, by necessity, have large CIs and should be applied cautiously. Moreover, the limited number of subjects with low BMI values suggests that very large subject samples are needed in future studies for model development or that subject evaluations include much leaner populations than those evaluated in the present 3-country study.

Last, our assumption is that percentage body fat is an improved phenotypic characteristic over BMI when functionality and mortality risk are considered. This hypothesis has some support (37), although additional studies with appropriate methods are needed to fully explore the range of issues surrounding body composition compared with body weight as “ponderal” measures. Moreover, visceral adiposity, separate from body composition or weight, is an independent predictor of morbidity and mortality (1) and development of improved clinical quantification methods remains a high priority.

**Conclusion**

This study presents a working approach to developing body fat ranges by linking current BMI guidelines with predicted percentage body fat. The developed provisional equations and tables in this report can fill an information gap because no comparable percentage body fat ranges exist for review for evaluation of potentially misclassified subjects referred for body-composition analysis. Our effort highlights important issues for future consideration, such as the appropriateness of increasing fatness with aging even when BMI remains constant, the causes of country or ethnicity differences in BMI–percentage body fat relations, whether misclassified subjects are more or less healthy than their counterparts with similar BMIs, and how to develop appropriate sampling strategies to prospectively develop percentage body fat ranges. These important issues require discussion, debate, and future investigation.

**REFERENCES**

1. US Department of Health and Human Services. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: the evidence report. Washington, DC: US DHHS, 1998. (98-4083.)
2. World Health Organization. Obesity: preventing and managing the global epidemic. Report of a WHO consultation on obesity. Geneva, June 3–5, 1997. Geneva: WHO, 1998.
3. Bray GA. Health hazards of obesity. *Endocrinol Metab Clin North Am* 1996;25:907–19.
4. Cole TJ. Weight-stature indices to measure underweight, overweight, and obesity. In: JH Himes, ed. *Anthropometric assessment of nutritional status*. New York: Wiley Liss, 1991:83–111.
5. Committee on Body Composition, Nutrition and Health of Military Women, Food and Nutrition Board, Institute of Medicine. *Assessing readiness in military women: the relationship of body composition, nutrition, and health*. Washington, DC: National Academy Press, 1998.
6. Sharp MD, Nindl C, Westphal KA, Friedl KE. The physical performance of female army basic trainees who pass and fail the army body weight and percent fat standards. In: Aghazadeh F, ed. *Advances in industrial ergonomics and safety VI*. London: Taylor and Francis, 1994:743–50.
7. Gledhill N, Jamnik VK. Development and validation of a fitness screening protocol for firefighter applicants. *Can J Sport Sci* 1992; 17:199–206.
8. Frisancho AR. *Anthropometric standards for the assessment of growth and nutritional status*. Ann Arbor, MI: University of Michigan Press, 1990.

9. Fuller NJ, Jebb SA, Laskey MA, Coward WA, Elia M. Four-compartment model for the assessment of body composition in humans: comparison with alternative methods, and evaluation of the density and hydration of fat-free mass. *Clin Sci* 1992;82:687-93.
10. Russell-Aulet M, Wang J, Thornton J, Pierson RN Jr. Comparison of dual-photon absorptiometry systems for total-body bone and soft tissue measurements: dual-energy X-rays versus gadolinium 153. *J Bone Miner Res* 1991;6:411-5.
11. Mazess RB, Barden HS, Bisek JP, Hanson J. Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *Am J Clin Nutr* 1990;51:1106-12.
12. Pierson RN Jr, Wang J, Colt EW, Neuman P. Body composition measurements in normal man: the potassium, sodium, sulfate and tritium spaces in 58 adults. *J Chronic Dis* 1982;35:419-28.
13. Jennings G, Bluck L, Wright A, Elia M. The use of infrared spectrophotometry for measuring body water spaces. *Clin Chem* 1999;45:1077-81.
14. Schoeller DA. Hydrometry. In: Roche AF, Heymsfield SB, Lohman TG, eds. *Human body composition*. Champaign, IL: Human Kinetics, 1996:25-44.
15. Akers R, Buskirk ER. An underwater weighing system utilizing "force cube" transducers. *J Appl Physiol* 1969;26:649-52.
16. Wilmore J. A simplified method for determination of residual lung volumes. *J Appl Physiol* 1969;27:96-100.
17. Jebb S, Elia M. Techniques for the measurement of body composition: a practical guide. *Int J Obes Relat Metab Disord* 1993;12:57-65.
18. Heymsfield SB, Wang ZM, Baumgartner RN, Ross R. Human body composition: advances in models and methods. *Annu Rev Nutr* 1997;17:527-58.
19. Heymsfield SB, Tighe A, Wang ZM. Nutritional assessment by anthropometric and biochemical methods. In: Shils ME, Olson JA, Shike M, eds. *Modern nutrition in health and disease*. 8th ed. Philadelphia: Lea and Febiger, 1992:812-41.
20. Flegal KM. Is an inverted weight-height index a better index of body fatness? *Obes Res* 1997;5:93S (abstr).
21. Baumgartner RN, Stauber PM, McHugh D, Koehler KM, Garry PJ. Cross-sectional age differences in body composition in persons 60+ years of age. *J Gerontol* 1995;50:M307-16.
22. Novak LP. Aging, total body potassium, fat-free mass, and cell mass in males and females between ages 18 and 85 years. *J Gerontol* 1972;27:438-43.
23. Cohn SH, Vaswani A, Aloia JF, Roginsky M, Zanzi I, Ellis KJ. Changes in body chemical composition with age measured by total body neutron activation. *Metabolism* 1976;26:85-96.
24. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness: age- and sex-specific prediction formulas. *Br J Nutr* 1991;65:105-14.
25. Forbes GB. *Human body composition*. New York: Springer Verlag, 1987.
26. Noppa H, Andersson M, Bengtsson C, Bruce A, Isaksson B. Longitudinal studies of anthropometric data and body composition. The population study of women in Gotenberg, Sweden. *Am J Clin Nutr* 1980;33:155-62.
27. Chien S, Peng MT, Chen KP, Huang TF, Chang C, Fang HS. Longitudinal studies on adipose tissue and its distribution in human subjects. *J Appl Physiol* 1975;39:825-30.
28. Steen B, Isaksson B, Svanborg A. Body composition at 70 and 75 years of age: a longitudinal study. *J Clin Exp Gerontol* 1979;1: 185-200.
29. Tzankoff SP, Norris AH. Longitudinal changes in basal metabolism in man. *J Appl Physiol* 1978;45:536-9.
30. Flynn MA, Nolph GB, Baker AS, Martin WM, Krause G. Total body potassium in aging humans: a longitudinal study. *Am J Clin Nutr* 1989;50:713-7.
31. Forbes GB, Reina JC. Adult lean body mass declines with age: some longitudinal observations. *Metabolism* 1970;19:653-63.
32. Tam SYM, Karlberg JPE, Kwan EYW, et al. Body mass index is different in normal Chinese and Caucasian infants. *J Pediatr Endocrinol Metab* 1999;12:507-17.
33. Gerace L, Aliprantis A, Russell M, et al. Skeletal differences between black and white men and their relevance to body composition estimates. *Am J Hum Biol* 1994;6:255-62.
34. Ortiz O, Russell M, Daley TL, et al. Differences in skeletal muscle and bone mineral mass between black and white females and their relevance to estimates of body composition. *Am J Clin Nutr* 1992;55:8-13.
35. Deurenberg P, Yap M, Van Staveren WA. Body mass index and percent body fat: a meta-analysis among different ethnic groups. *Int J Obes Relat Metab Disord* 1998;22:1164-71.
36. Deurenberg P, Deurenberg M, Yap M, Wang J, Lin FP, Schmidt G. The impact of body build on the relationship between body mass index and percent body fat. *Int J Obes Relat Metab Disord* 1999;23:537-42.
37. Allison DB, Zannolli R, Faith MS, et al. Weight loss increases and fat loss decreases all-cause mortality rate: results from two independent cohort studies. *Int J Obes Relat Metab Disord* 1999;23:603-11.