

## Sensitivity and Specificity of the Body Mass Index to Assess Low Percent Body Fat in African Women

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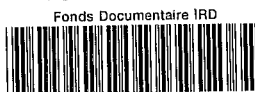
**ABSTRACT** The objective of this study was to evaluate the ability of the body mass index (BMI, kg/m<sup>2</sup>) to reflect low percent body fat (%BF) in a population with a rather mild but widespread prevalence of low BMI. A sample of 586 women was studied in the Plateau Koukouya, a rural area of the Republic of Congo, Central Africa. Percent BF was estimated from bio-electrical impedance (BIA). BIA parameters were assumed to reflect lean body mass. The correlation between %BF and BMI was high ( $r = 0.84$ ;  $P < 0.001$ ). Low %BF or low BIA parameters were defined as the first quartile of the distribution. Sensitivity, specificity, positive and negative predictive value of BMI  $< 18.5$ , an accepted international cutoff for thinness, in relation to %BF was 58.5%, 93.6%, 75.4%, and 87.1%, respectively. A continuous sensitivity/specificity analysis (receiver operator characteristic [ROC] curves) for characterizing low %BF or low BIA parameters was done for a large range of BMI values. ROC curve analysis for %BF suggested that an acceptable trade-off between sensitivity (89.8%) and specificity (77.9%) occurred at a BMI of 19.7 kg/m<sup>2</sup>. However, the positive predictive value was low (57.6%). For the prediction of low BIA parameters, results were similar, showing moderate sensitivity and high specificity for BMI  $< 18.5$ , a cutoff point of BMI = 19.6, and low positive predictive values ( $< 48\%$ ). The data suggest that BMI was not a good predictor of low %BF. This is consistent with the assumption of a decrease in both fat and fat free body mass in cases of low BMI. *Am. J. Hum. Biol.* 12:25-31, 2000. © 2000 Wiley-Liss, Inc.

The decrease of body weight and variation in body composition associated with inadequate food and energy supplies is of great concern in developing countries. The body mass index (BMI) or Quetelet's index, defined as body-weight/height<sup>2</sup> (Quetelet, 1869), is used in epidemiological settings as an indicator of chronic energy deficiency or thinness in adults (James et al., 1988; Ferro-Luzzi et al., 1992; WHO, 1995). When weight is lost and BMI decreases, both adipose tissue and lean tissue (muscle) are used for fuel, but the proportion of lean tissue lost depends on the amount of fat in the body: the greater the mass of adipose tissue, the smaller the loss of lean tissue on starvation (Forbes, 1987). There are increasing

amounts of lean tissue lost as body weight and BMI fall. Although a case can be made for the BMI as a useful general index of the mass of lean and fat tissue, it is also true that in individuals with the same BMI there will be different proportions of lean and fat tissues. The most obvious failure of BMI to characterize thinness is to not differentiate between low lean and low-fat individuals. Different biological processes or health out-

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comes can be involved in these different cases.

Correlations of BMI with estimates of fat and lean tissue mass in individuals from developing countries show that BMI reflects both fat and fat-free mass (Norgan, 1990; Shetty and James, 1994). Luke et al. (1997) found that within populations of American, Jamaican, and Nigerian Blacks, BMI was a relatively good predictor of level of body fat. This substantiated the assumption that BMI values below a certain cutoff point could reflect low fat mass. Because BMI does not measure fat mass or percentage fat and because there are no clearly established cutoff points for fat mass or percentage fat that can be translated into cutoffs for BMI, we decided to test the ability of BMI to predict low percent body fat by sensitivity/specificity analysis. Information on the sensitivity and specificity of BMI would help to clarify the clinical effectiveness of BMI in correctly identifying truly thin individuals. For epidemiological studies with large samples, bioelectrical impedance analysis (BIA) appears to be an ideal tool. BIA provides a rapid, noninvasive, and relatively accurate estimate of body composition (Foster and Lukaski, 1996). An advantage of BIA over multiple skinfolds, the technique most commonly used in field studies (Durnin and Womersley, 1974), is that results may theoretically be less dependent on the distribution of fat over the body.

The primary purpose of this study was to examine the sensitivity and specificity of BMI in African women in order to detect low percent body fat as calculated from BIA.

## SUBJECTS AND METHODS

### *Subjects*

A cross-sectional survey was conducted in April, 1992, in 30 villages in the Plateau Koukouya, a remote rural area of the Republic of Congo, Central Africa. As part of a nutritional assessment survey, a representative sample of children <5 years old was randomly selected by two-stage cluster sampling. Based on the results of the last national census, 30 villages were randomly selected with probability proportional to size. Then, 30 children <5 years old were randomly selected in each village. This study is based on the 586 mothers of the children <4 years old sampled (excluding those who were pregnant when the survey was imple-

mented). Informed consent of subjects was obtained before performing anthropometry and BIA.

### *Anthropometry*

Measurements were made by trained personnel using standard procedures (Lohman et al., 1988). Body weight was measured to within 200 g with calibrated electronic scales, and height to the nearest millimeter with a portable gauge. BMI was derived, body mass/stature<sup>2</sup> (kg/m<sup>2</sup>). In keeping with Ferro-Luzzi et al. (1992), we considered women with BMI <18.5 as potential cases of thinness. Age was obtained by interview and verified with civil status documents or birth certificates whenever possible. Two age groups were established using the cutoff point of age 25 years, as the use of the same BMI cutoff points for thinness in these age groups is still questionable (WHO, 1995).

### *Bioelectrical impedance analysis*

BIA was performed on the left side of the body with a body composition analyzer (Model TVI-10, Danninger Medical, Columbus, OH, USA) with a four-electrode arrangement. The electrodes were paired, one pair acting as current electrodes, the other pair acting as detector electrodes. Electrodes were placed on the hand, wrist, foot, and ankle of each subject according to the manufacturer's guidelines. Subjects were supine with their hands and thighs apart. Measurements were performed each day between 8:30 AM and 2:00 PM at a relative constant outside temperature. The day of the survey, subjects were waiting for the measurer at home before going to the fields (91% of the women were agriculturists), so they had not engaged in agricultural activity since the previous day. In the field context, it was not possible to meet the other usual conditions for BIA measurements, such as no eating or drinking within 4 hours of the test or recommendations on voiding the bladder beforehand. The resistance (R) value for each subject was read to the nearest 0.1 $\Omega$  from a digital display and recorded. The calibration of the instrument was checked daily with standard resistors included in the analyzer. Only measurements at the frequency of 50 kHz were used. Lean body mass (LBM) was calculated using the generalized sex-specific regression equation of Segal et al. (1988), which has been cross-validated in four laboratories and used in a

TABLE 1. Anthropometric and bioelectrical impedance (BIA) characteristics (mean (SD)) by quartile of body mass index (BMI, kg/m<sup>2</sup>)\*

BMI quartiles	(mean; SD)	n	Weight kg	Height cm	BIA %BF %	BIA LBM kg	Height <sup>2</sup> /R cm <sup>2</sup> /Ω*	R Ω	1,000/R Ω
First	(17.8; 0.8)	146	44.6 (4.1)	158.2 (6.1)	21.1 (3.5)	35.2 (3.5)	36.1 (4.6)	701 (73)	1.44 (0.14)
Second	(19.6; 0.4)	147	49.2 (4.2)	158.3 (6.4)	23.9 (2.4)	37.4 (3.5)	38.5 (4.6)	657 (49)	1.53 (0.11)
Third	(20.9; 0.4)	147	52.2 (3.4)	157.9 (4.9)	26.2 (2.3)	38.6 (2.6)	39.8 (4.0)	632 (55)	1.59 (0.14)
Fourth	(23.7; 2.1)	146	59.2 (7.8) <sup>1</sup>	157.9 (5.4)	30.9 (3.5) <sup>1</sup>	40.8 (3.2) <sup>1</sup>	41.9 (4.6) <sup>1</sup>	601 (53) <sup>1</sup>	1.68 (0.15) <sup>1</sup>
Total	(20.5; 2.4)	586	51.4 (7.2)	158.1 (5.7)	25.5 (4.7)	38.0 (3.8)	39.1 (5.0)	647 (69)	1.56 (0.16)

\*%BF, percent body fat; LBM, lean body mass; R, resistance.

<sup>1</sup>P < 0.05 for comparison within the four quartiles.

large study group (n = 1,567, of which 498 were women). Body fat from BIA was calculated as the difference between body weight and LBM. Percent body fat (%BF) was calculated.

Two BIA parameters were calculated: 1/R (Ω<sup>-1</sup>) and height<sup>2</sup>/R (cm<sup>2</sup>/Ω). For practical reasons, the inverse of resistance was multiplied by 1,000 and expressed as 1,000/R. Electrical theory indicates that the term L<sup>2</sup>/R is related to the volume of the conducting medium, where L is its length or height and R is the resistance. In man, the value of height<sup>2</sup>/R has been found to correlate highly with laboratory estimates of total body water (volume) and fat-free mass (Lukaski et al., 1985; Segal et al., 1985; Kushner and Schoeller, 1986). To create an LBM index providing the volume of LBM independent of height, we divided the volume index (height<sup>2</sup>/R) by height<sup>2</sup> to obtain the index 1/R.

### Analysis

The Pearson correlation was computed between BMI and %BF. The range for %BF within each quartile of BMI was calculated. The upper limit of the first quartile of %BF was chosen as the cutoff point to define low %BF. In the same way, the upper limit of the first quartile was chosen as the cutoff point to define low BIA parameters.

Based on the results from a contingency analysis, specificity, sensitivity, and predictive values of BMI were computed for low %BF (Bouyer et al., 1995). Sensitivity is the probability for subjects to have a low BMI when they have low %BF. Specificity is the probability to have a normal (i.e., not low) BMI when subjects have a normal %BF. Positive and negative predictive values were also calculated. A positive predictive value is the proportion (×100) of subjects having a low %BF relative to the subjects having a low BMI. A negative predictive

value is the proportion (×100) of subjects having a normal (i.e., not low) %BF relative to subjects having a BMI above the cutoff value.

Sensitivity/specificity analysis used a cutoff of 18.5 kg/m<sup>2</sup> for BMI, an accepted international cutoff for thinness. Then ROC curves were obtained by plotting sensitivity versus 1-specificity when varying BMI threshold (Vinatier and Monnier, 1988). In brief, ROC curves were used to set cutoff points by portraying the trade-offs between improving a measure's sensitivity or specificity. The best cutoff point is when the sum of sensibility + specificity is the highest. We set a series of cutoffs for BMI in increments of 0.1 over the interval of 15.2 to 33.8 (kg/m<sup>2</sup>).

Statistical software used for data entry, validation, and analysis was Epi-Info (Dean et al., 1994) and the SAS system, release 6.11 (SAS, 1989). Values are expressed as means and standard deviations. Differences in variables were tested using analysis of variance. P < 0.05 was regarded as significant.

### RESULTS

Characteristics of the subjects are shown in Table 1. Mean age was 29.4 years (SD 8.5, range 15–59). Mean BMI was 20.5 kg/m<sup>2</sup> (SD 2.4, range 15.2–33.8). As expected, body weight significantly increased across BMI quartiles, as did %BF and LBM. BIA parameters also increased significantly across BMI quartiles, while R decreased. According to the BMI classification of <18.5, 19.5% of subjects were thin. Because of the cutoff based on the first quartile, 25% of subjects had low %BF or low BIA parameters.

The number and percentage of women in the four %BF quartiles within each BMI quartile are presented in Table 2. There was a significant difference between cell frequency as shown by chi-square analysis (P <

TABLE 2. Distribution of subjects in percent body fat (%BF) quartiles and range of %BF across BMI quartiles

BMI quartiles (kg/m <sup>2</sup> )	%BF quartiles				Total sample (n = 586) %BF range
	First (n = 146) [9.5; 22.5[	Second (n = 147) [22.5; 25.2[	Third (n = 146) [25.2; 28.4[	Fourth (n = 147) [28.4; 42.5[	
	(n) column percentage				
First (n = 146) [15.2; 18.9[	(101) 69.1%	(33) 22.5%	(7) 4.8%	(5) 3.4%	9.5; 31.9
Second (n = 147) [18.9; 20.3[	(42) 28.8%	(63) 42.9%	(34) 23.3%	(8) 5.4%	18.5; 30.5
Third (n = 147) [20.3; 21.7[	(3) 2.1%	(49) 33.2%	(70) 47.9%	(25) 17.0%	21.5; 33.4
Fourth (n = 146) [21.7; 33.8[	(0) 0.0%	(2) 1.4%	(35) 24.0%	(109) 74.2%	23.6; 42.5

0.001). It is apparent that BMI may be reasonably good at classifying individuals into the correct %BF group for the lowest and the highest BMI quartiles, with over 69% correctly classified; classification in the second and third %BF quartiles from BMI, however, was less satisfactory. As BMI increased, there was a decrease in cases with %BF <22.5% (first quartile) and, in contrast, there was an increase in cases with %BF >28.4% (fourth quartile).

In the total sample, the correlation between %BF and BMI was high ( $r = 0.84$ ;  $P < 0.001$ ). Table 2 shows the ranges of %BF across the four quartiles of BMI. It is apparent that almost any value of %BF is possible within each quartile of the BMI, especially for higher values.

Values corresponding to the upper limit of the first quartile were 22.5% for %BF, 35.6 cm<sup>2</sup>/Ω for height<sup>2</sup>/R, and 1.48 Ω<sup>-1</sup> for 1,000/R. Table 3 shows the results of the contingency analysis for the BMI cutoff of 18.5 in relation to %BF and for the BMI cutoff derived from the ROC analysis in the total sample and by age. In the total sample, sensitivity of BMI = 18.5 in relation to %BF was low and specificity was very high. The positive predictive value and negative predictive value were relatively high. Figure 1 presents the ROC curve. Based on the trade-offs between improving the sensitivity and specificity of BMI, the cutoff value was BMI = 19.7 kg/m<sup>2</sup>, leading to 39.1% of women with a positive test. With this cutoff, sensitivity of BMI in relation to %BF increased but the positive predictive value was low. Mean BMI and mean %BF were similar ( $P > 0.05$ ) in women <25 years (20.6, SD 2.1 kg/m<sup>2</sup>; 25.0%, SD 4.4%, respectively) and in the older women (20.4, SD 2.6 kg/m<sup>2</sup>; 25.8% SD 4.8%, respectively). Sensitivity/specificity analysis by age showed similar results in the oldest women compared to the total sample, except that the sensitivity was 10% higher when BMI = 18.5. In contrast,

we found a lower sensitivity of BMI = 18.5 in the youngest women, as well as a higher BMI cutoff defined by the ROC analysis. However, in all cases the BMI cutoff derived from the ROC curve was higher than 18.5 and the positive predictive value remained less than 58%.

The BIA prediction equation used in this study has been cross-validated, but not specifically within African populations. No specific BIA prediction formula exists at present for African populations. For that reason, we also used two BIA parameters, height<sup>2</sup>/R and 1,000/R, as indices of LBM. Table 4 shows the results of the sensitivity/specificity analysis of BMI in relation to the BIA indices. For both BIA indices, results for BMI = 18.5 showed that sensitivity was low (<46%) and specificity was high (>87%). When the BMI cutoffs used were the ones derived from the ROC analysis, sensitivity increased and specificity decreased. In all cases, the predictive values were lower than those obtained in relation to %BF.

## DISCUSSION

Discrimination of variation in lean and fat mass is of particular interest for investigating the nutritional status of adult populations, particularly in conditions where chronic energy deficiency is not uncommon. Thus, we examined the sensitivity and specificity of BMI, a commonly used weight-height index of thinness, to detect low %BF in a population of African women with a mild to widespread prevalence of low BMI.

Classification by BMI can be assumed to correspond to variation of both fat and lean compartments because large decreases in body weight do not involve fat mass only. Therefore, it was of interest to contrast the variation according to quartiles of both BMI and %BF. The quartiles corresponded clearly to increased proportions of body fat. However, the distributions showed that

TABLE 3. Sensitivity/specificity analyses of the body mass index (BMI) to detect low percent body fat (%BF) in the total sample and by age

	Total sample (n = 586)		Age <25 years (n = 220)		Ages $\geq$ 25 years (n = 366)	
	Detection of %BF <22.5 <sup>1</sup>		Detection of %BF <22.5 <sup>1</sup>		Detection of %BF <22.5 <sup>1</sup>	
	BMI < 18.5	BMI < 19.7 <sup>2</sup>	BMI < 18.5	BMI < 20.2 <sup>2</sup>	BMI < 18.5	BMI < 19.5 <sup>2</sup>
Sensitivity	58.5%	89.8%	42.9%	100%	68.1%	91.2%
Specificity	93.6%	77.9%	96.3%	72.6%	92.0%	77.8%
Positive predictive value	75.4%	57.6%	80.0%	55.4%	73.8%	57.6%
Negative predictive value	87.1%	95.8%	83.2%	100%	89.7%	96.4%

<sup>1</sup>Cutoff corresponding to the upper limit of the first quartile.

<sup>2</sup>Cutoff based on the trade-off between improving BMI's sensitivity and specificity (ROC analysis).

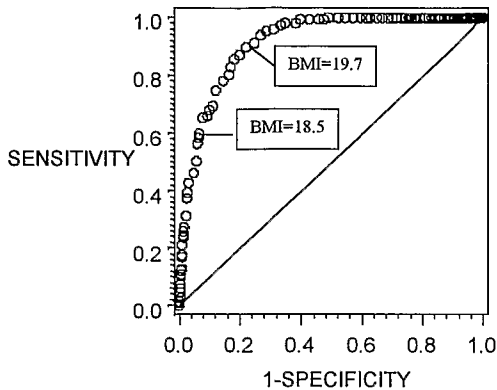


Fig. 1. ROC curve for the prediction of low %BF (<22.5) by BMI in rural African women.

BMI was not highly related to %BF at each level. This suggests that a wide range of %BF can be encountered for a same value of BMI. In the first BMI quartile, almost one-third of subjects had %BF higher than that corresponding to the first %BF quartile, suggesting that a low BMI is not always related to a low %BF. In these women, low BMI is assumed to be due to decreased LBM, because body weight for height as assessed by BMI was low. In the fourth BMI quartile, one-quarter of subjects had less %BF than that corresponding to the fourth %BF quartile, and had probably relatively high LBM.

The sensitivity/specificity analysis revealed that BMI for the currently proposed cutoff of 18.5 had moderate sensitivity and high specificity in relation to the %BF cutoff value of 22.5. BMI <18.5 could identify only 59% of subjects who had truly a %BF <22.5. However, as shown by the positive predictive value, almost one-quarter of subjects with a low BMI had a %BF >22.5. In contrast, the high negative predictive value in-

dicated that very few subjects with BMI  $\geq$ 18.5 had a low %BF.

The ROC analysis showed that the best compromise between sensitivity and specificity, based on our database, yielded a BMI cutoff value of 19.7 kg/m<sup>2</sup> for low %BF; this is higher than the one currently used to identify thinness. This higher cutoff value would identify heavier individuals who would otherwise be missed by the usual thinness cutoff. In relation to low %BF, a BMI cutoff of 19.7 produced increased sensitivity (90% vs. 59%) and moderately decreased specificity (78% vs. 94%). However, the positive predictive value was lower (58% vs. 75%), meaning that 42% of the women detected as positive with BMI <19.7 did not, in fact, have a low %BF. This suggests that a low BMI was not associated with a low %BF in almost half of the cases for whom the low BMI corresponded rather to a low LBM. Of course, this cutoff value was derived on the basis of an equal cost for classifying erroneously low or normal %BF, and it could be moved further, according to the importance one attaches to this. But, it is still unclear how such a higher BMI cutoff value would in fact correlate with clinical and nutritional status. Nevertheless, a BMI cutoff needs to relate to some measure of functional impairment, and the 19.7 cutoff cannot be accepted without testing its relationship to measures of, for example, morbidity or work capacity.

Because of the difficulty in establishing appropriate limits of BMI in young adults (WHO, 1995), we also conducted the sensitivity/specificity analysis in the sample divided into two age groups above and below age 25 years. Mean BMI and %BF were similar in these age groups. Analysis by age showed a lower sensitivity of BMI cutoff of 18.5 in the younger women, as well as a higher BMI cutoff defined by the ROC

TABLE 4. Sensitivity/specificity analyses of the body mass index (BMI) to detect low values of BIA parameters\*

	Detection of height <sup>2</sup> /R < 35.6 <sup>1</sup>		Detection of 1,000/R < 1.48 <sup>1</sup>	
	BMI < 18.5	BMI < 19.6 <sup>2</sup>	BMI < 18.5	BMI < 19.6 <sup>2</sup>
Sensitivity	40.4%	64.4%	45.6%	69.4%
Specificity	87.5%	72.5%	89.3%	74.3%
Positive predictive value	51.8%	43.7%	58.8%	47.4%
Negative predictive value	81.6%	86.0%	83.1%	87.9%

\*BIA, bioelectrical impedance analysis; R, resistance.

<sup>1</sup>Cutoff corresponding to the upper limit of the first quartile.

<sup>2</sup>Cutoff based on the trade-off between improving BMI's sensitivity and specificity (ROC analysis).

analysis. However, positive predictive values were similar in either age group.

These results show that BMI was a relatively poor predictor of low %BF in this population. This is consistent with the assumption that a decrease in BMI cannot discriminate between variation in lean or fat mass, even if correlations between BMI and body compartments are high (Norgan and Ferro-Luzzi, 1982; Norgan, 1990; Shetty and James, 1994). In our study, there was a high correlation between BMI and %BF in the total sample.

An obvious shortcoming of the present study is that the %BF cutoff value was chosen somewhat arbitrarily from the division into quartiles, and not in relation to a body fat level associated with various disease risk factors. Indeed, although the range and upper limit of %BF compatible with good health have been extensively examined, less attention has focused on using %BF in undernourished or underweight subjects and on its ability to predict morbidity/mortality risks in people suffering from food restriction. No definition of thinness through %BF exists at present. A cautionary note is that the relation between BMI and %BF differs in people of different ethnic origins (Norgan, 1990). Thus, the conclusions of the present study are relevant to rural African women.

It has also been recommended that calculations of body composition from the basic electrical measurements should include population-specific equations (NIH, 1996). The prediction equation used in this study has been cross-validated, but not specifically within African populations. No specific BIA prediction formula exists at present for African populations. However, there is one BIA equation developed specifically for African-American women (Wang et al., 1995), but Ainsworth et al. (1997) showed that it underpredicted the fat-free mass of Black

women by about 4 kg. Such an underestimation of the fat-free mass in Black women could explain the relatively high %BF (25.5%) for a BMI of 20.5 kg/m<sup>2</sup> in our subjects, compared to the data reported by Norgan (1994). For this reason, we also used two BIA parameters as indices of LBM and tested the ability of BMI to predict their classification. For both BIA indices, results for BMI = 18.5 were lower than those obtained for low %BF, and BMI cutoffs derived from ROC curves were the same. BMI appears to be a poor predictor of low %BF, as well as of low BIA indices of LBM, because the positive predictive value remained low in all cases. The predictive values are largely dependent on the prevalence of low %BF in this population. However, our sample reflects a situation commonly encountered in rather isolated rural African areas, so that the results may be meaningful for a wider context.

These results are consistent with the fact that mean level of body fat varied substantially at similar levels of BMI between individuals. A single measurement of weight or BMI is of limited use for assessing an individuals' risk of ill-health or if she is likely to benefit from medical intervention or supplementary feeding. Easy-to-use methods of body composition measurement are needed for a more complete evaluation of thinness in epidemiological settings. However, even if BIA is a noninvasive and inexpensive technique that can be used in the field, the required portable analyzer is at present unlikely to be affordable in the contexts in which it is most likely to be useful. Although difficult to perform in these situations, studies are needed for the validation of BIA body composition measurement in African populations and the development of new population-specific prediction formulas.

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