

Limits of Body Mass Index to Detect Obesity and Predict Body Composition

David C. Frankenfield, MS, RD, William A. Rowe, MD, Robert N. Cooney, MD,
J. Stanley Smith, MD, and Dolores Becker, MS, RD

From the Department of Clinical Nutrition and the Divisions of Gastroenterology and Trauma, Penn State's Milton S. Hershey Medical Center, Pennsylvania State University College of Medicine, Hershey, Pennsylvania, USA

Body mass index (BMI) is commonly used to identify obesity. In this study, we determined how accurately BMI could determine body composition and identify obese from non-obese individuals. Fat-free mass and body fat were determined with bioelectrical impedance. Adiposity was calculated as body fat per body mass and as body fat divided by body height (m^2). Obesity was defined as a BMI of at least 30 kg/m^2 or an amount of body fat of at least 25% of total body mass for men and at least 30% for women. Obesity as defined by percentage of body fat was always present with a BMI of at least 30 kg/m^2 . However, 30% of men and 46% of women with a BMI below 30 kg/m^2 had obesity levels of body fat. The greatest variability in the prediction of percentage of body fat and body fat divided by height (m^2) from regression equations using BMI was at a BMI below 30 kg/m^2 . In conclusion, using impedance-derived body-fat mass as the criterion, people with BMI of at least 30 kg/m^2 are obese. However, significant numbers of people with a BMI below 30 kg/m^2 are also obese and thus misclassified by BMI. Percent of body fat and body fat divided by height (m^2) are predictable from BMI, but the accuracy of the prediction is lowest when the BMI is below 30 kg/m^2 . Therefore, measurement of body fat is a more appropriate way to assess obesity in people with a BMI below 30 kg/m^2 . *Nutrition* 2001;17:26–30. ©Elsevier Science Inc. 2001

Key words: obesity, body mass index, bioelectrical impedance

INTRODUCTION

Obesity is a common condition in many societies, and its incidence is rising.^{1,2} Numerous chronic health conditions (e.g., diabetes, hypertension, heart disease, sleep apnea, and degenerative joint disease) are associated with obesity, and mortality rates increase with increasing body mass.^{3–6} Consequently, diagnosis and treatment of obesity is a major health issue.

Obesity is defined as an excess of body fat. Body fat is difficult to measure. However, increased body fat is usually accompanied by increased total body mass, so indices of relative weight are commonly used to diagnose obesity and to track progress in the treatment of the obese person.^{1–5}

One of the most commonly used indices of relative weight is the body mass index (BMI; sometimes referred to as the Quetelet index).⁷ BMI (body mass in kilograms divided by height, or meters, squared) was not originally intended as an index of obesity but is now commonly employed as such in epidemiologic studies, where it accurately predicts obesity-related morbidity and mortality.^{3–5} A BMI of 30 kg/m^2 is considered the threshold of obesity.² However, the accuracy of BMI as a body-composition marker is controversial.^{8–12} Some have suggested that BMI inadequately predicts percentage of body fat,^{8–10} whereas others have suggested that BMI may be useful to predict body fat indexed to height but not to predict percentage of body fat.^{11,12} The issue of whether indices of overweight predict body composition is impor-

tant because body composition (i.e., adiposity) rather than excess body mass is the more important health risk.⁶ The current study was undertaken to determine whether BMI accurately identifies individuals as obese or not obese and to investigate the ability of BMI to predict body-fat content measured by bioelectrical impedance.

METHODS

Our institutional review board approved the current study. Subjects were recruited by advertisements in a medical center (consisting of a hospital, clinics, a medical college and biomedical research building, hospital-associated fitness center, and an obesity clinic). Participation in the study was not limited by race, sex, or body size. The study sample was restricted to ambulatory adults (age > 18 y). Amputees were excluded. Informed consent was obtained from each subject before the study. All subjects were instructed to fast and to avoid exercise for 12 h before being measured. Subjects traveled to the research site on the day of testing. Tests were conducted generally between 7:00 and 9:00 AM (up to 11:00 AM).

Body Mass Index

Height (stadiometry) and body mass (balance scale) were measured without shoes or excess clothing (coats, sweaters, vests), but subjects were not unclothed during measurement of mass. Height was recorded to the nearest 0.1 cm and mass to the nearest 0.1 kg. From these data, BMI was calculated (mass/height, or kg/m^2).

Fat-Free Mass and Body Fat

After measurement of height and mass, subjects were instructed to assume a resting supine position on a cot or bed for 30 min, and

Correspondence to: David C. Frankenfield, MS, RD, Department of Clinical Nutrition, Penn State's Milton S. Hershey Medical Center, PO Box 850, Hershey, PA 17033, USA. E-mail: dfrankenfield@psu.edu

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TABLE I.

Variable	Men (n = 53)				Women (n = 88)			
	Mean	SEM	Minimum	Maximum	Mean	SEM	Minimum	Maximum
Height (cm)	179.0	1.3	164.0	194.0	163.2	0.8	144.8	186.7
Body mass (kg)	109.8	8.2	58.5	329.6	84.1	3.7	39.2	203.2
Age (years)	40	2.2	18	78	39	1.4	19	75
Body mass index (kg/m ²)	34.0	2.4	18.8	93.4	31.5	1.5	15.9	79.3
Fat-free mass (kg)	72.9	3.2	45.9	154.9	49.0	1.1	28.7	80.4
Body fat (kg)	36.9	5.2	7.1	174.7	35.3	2.7	5.8	122.8
%Body fat (wt/wt)	28.7	1.5	9.9	53.0	37.7	1.2	11.6	60.4
Body fat/height ² (kg/m ²)	11.4	1.5	2.1	49.5	13.3	1.0	1.9	48.0

then bioelectrical impedance measurements were made. A single-frequency bioelectrical impedance plethysmograph was used (BIA 101Q, RJL Industries, Detroit, MI, USA). Standard electrocardiographic electrodes were placed on the dorsal aspects of the hands and feet. Isopropyl alcohol was used to clean each site of electrode attachment. Source leads were attached to the distal electrodes, and recording leads were attached to the proximal electrodes of the hand and foot. The subjects' legs were parted, and the arms were adducted approximately 30 degrees to avoid skin-to-skin contact. If limbs could not be spread wide enough apart to prevent skin-to-skin contact, a dry towel was placed to achieve separation. Impedance measurements (resistance and reactance) were made and recorded in triplicate, and the mean was calculated.¹³ Fat-free mass was calculated from the general equations described by Segal et al.¹⁴:

$$\text{male: fat-free mass (kg)} = 22.668 + 0.00132 (\text{height}^2) - 0.04394 (\text{resistance}) + 0.3052 (\text{body mass}) - 0.1676 (\text{age})$$

$$\text{female: fat-free mass (kg)} = 14.594 + 0.00108 (\text{height}^2) - 0.0209 (\text{resistance}) + 0.23199 (\text{body mass}) - 0.06777 (\text{age})$$

body fat was determined mathematically as the difference between total body mass and impedance-derived fat-free mass.

Indexing Body Fat

Percentage of body fat was computed as the ratio of body fat to total body mass. Body fat was also normalized to height squared (kilograms of body fat per meter squared of height).^{11,12}

Definitions of Obesity

A BMI of at least 30 kg/m² is considered obese in men and women.² The alternative definition of obesity is based on percentage of body fat. Body fat greater than or equal to 25% of body weight in men and greater than or equal to 30% in women is considered obese.¹⁵

Statistics

Percentage of body fat and body fat/height² were analyzed as functions of BMI by using linear and polynomial regressions (Minitab release 12, Minitab, State College, PA, USA), resulting in predictive equations of percentage of body fat and body fat/height² from the BMI. Comparisons of group means were made with Student's unpaired *t* test. *P* < 0.05 was accepted as statistically significant.

RESULTS

Fifty-three men and 88 women participated in the study. The study sample population was largely white (98%; 4% of whom were Australian or European students studying in the United States, 3% of whom were of Hispanic ethnicity). A wide range of age and body size was represented in the sample (Table I). The men tended to be larger and leaner than the women, but age (mean and range) was similar.

Impedance values for men were as follows: resistance = 423 ± 11 Ω, reactance = 51 ± 2 Ω. Corresponding measurements for the women were 550 ± 11 Ω and 60 ± 1 Ω (*P* < 0.0001). Impedance data broken down by BMI and percentage of body fat are presented in Table II. Statistically significant differences in resistance and reactance occurred between the obese and non-obese groups, no matter how obesity was defined (i.e., by BMI or percentage of body fat).

Forty percent of all men and 38% of all women had a BMI of at least 30 kg/m², thus qualifying as obese according to BMI guidelines. No subject with a BMI of at least 30 kg/m² had a percentage of body fat below 25% (men) or 30% (women). However, 30% of the men and 46% of the women who had a BMI below 30 kg/m² (and therefore were considered not obese by that standard) had a percentage of body fat that was high enough to qualify them as obese using the bioelectrical-impedance criteria.

TABLE II.

	IMPEDANCE VALUES FOR SUBJECTS GROUPED BY BODY MASS INDEX AND PERCENTAGE OF BODY FAT (MEAN ± SEM)	
	Resistance (Ω)	Reactance (Ω)
Men		
Body mass index < 30 kg/m ²	466 ± 8*	57 ± 1.9*
Body mass index ≥ 30 kg/m ²	356 ± 15	42 ± 2.8
Body fat < 25% of body wt	471 ± 10†	60 ± 1.6†
Body fat ≥ 25% of body wt	385 ± 14	44 ± 2.4
Women		
Body mass index < 30 kg/m ²	607 ± 9*	65 ± 1.3*
Body mass index ≥ 30 kg/m ²	455 ± 14	52 ± 2.0
Body fat < 30% of body wt	615 ± 13‡	68 ± 1.8‡
Body fat ≥ 30% of body wt	524 ± 15	57 ± 1.5

* *P* < 0.0001 versus body mass index ≥ 30 kg/m² group of same sex.

† *P* < 0.0001 versus body fat ≥ 25% group.

‡ *P* < 0.0001 versus body fat ≥ 30% group.

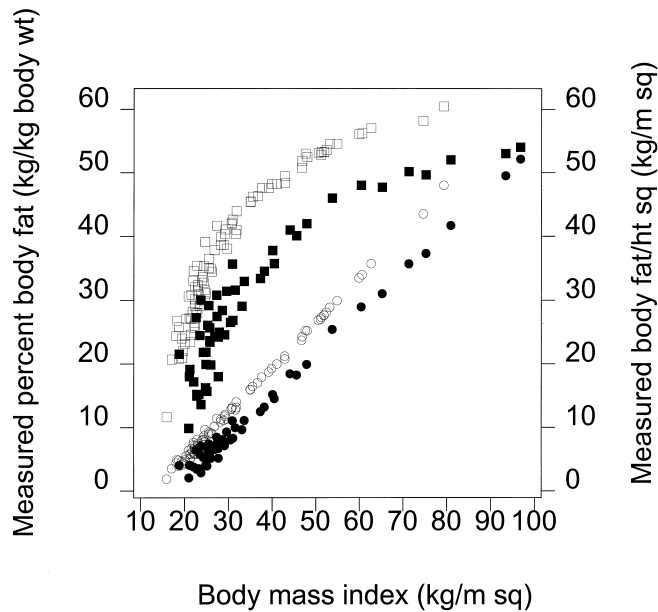


FIG. 1. Quadratic and linear relations relating body mass index to percentage of body fat and body fat divided by height (m^2) in men and women ($P < 0.0001$ for both sexes). Solid circles, body fat divided by height (m^2) in men; open circles, body fat divided by height (m^2) in women; solid squares, percentage of body fat in men; open squares, percentage of body fat in women.

The lowest BMI at which all subjects were obese by impedance criteria was 30 kg/m^2 for men and 25 kg/m^2 for women. The lowest BMI at which obesity levels of percentage of body fat were detected was 22.6 kg/m^2 in men and 20.1 kg/m^2 in women.

Body Mass Index to Predict Body Composition

The relation between BMI, percentage of body fat, and body fat/height² for the study sample is shown in Figure 1. As one would expect, the relation between BMI and percentage of body fat was quadratic. The regression equations were as follows:

men: % body fat (kg/kg) =
 $-0.09 + 0.0149 (\text{BMI}) - 0.00009 (\text{BMI}^2)$
 ($r^2 = 0.886$ versus 0.80 to fit a linear model) (1)

female: % body fat (kg/kg) =
 $-0.08 + 0.0203 (\text{BMI}) - 0.000156 (\text{BMI}^2)$
 ($r^2 = 0.942$ versus 0.85 to fit a linear model) (2)

In contrast, the comparison of BMI and body fat/height² yielded a strong linear association (Fig. 1). The regression equations for predicting body fat/height² from BMI were:

men: body fat/height² (kg/m^2) = $-10.5 + 0.642 (\text{BMI})$
 $r^2 = 0.992$ (3)

women: body fat/height² (kg/m^2) = $-9.3 + 0.714 (\text{BMI})$
 $r^2 = 0.997$ (4)

Figures 2 and 3 show the differences between measured and predicted body fat (from equations 1 to 4) across the range of BMI. Variation in the difference between measured and calculated percentage of body fat tended to be greater below a BMI of approximately 30 kg/m^2 , although variation was significant throughout

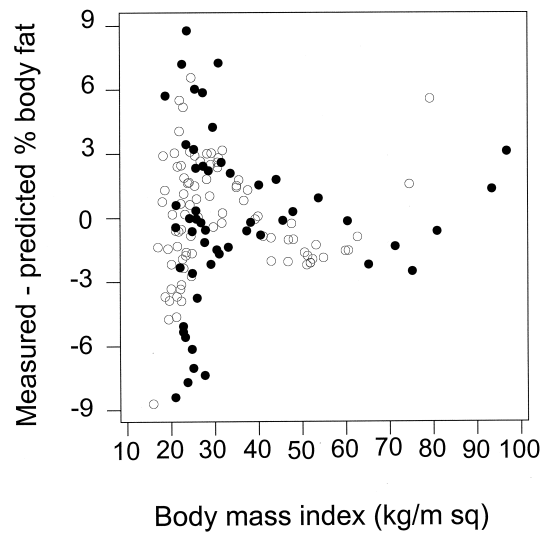


FIG. 2. Plot of the difference between measured and predicted percentages of body fat (equations 1 and 2) over the range of body mass index in the study (solid circles, men; open circles, women).

the range of BMI (Fig. 2). The coefficient of determination for predicted versus actual percentage of body fat in men with a BMI below 30 kg/m^2 was 0.299 versus 0.941 in men with a BMI above 30 kg/m^2 (corresponding r^2 values for women were 0.81 and 0.922 , respectively). There was less variation in differences between measured and predicted body fat/height². The r^2 value for predicted versus measured body fat/height² was 0.567 in men with a BMI below 30 kg/m^2 and 0.996 in men with a BMI above 30 kg/m^2 (corresponding values for women were 0.933 and 0.998 , respectively).

DISCUSSION

In the current study, all subjects who were obese by the BMI criterion ($\text{BMI} \geq 30 \text{ kg/m}^2$) were also obese by the bioelectrical-

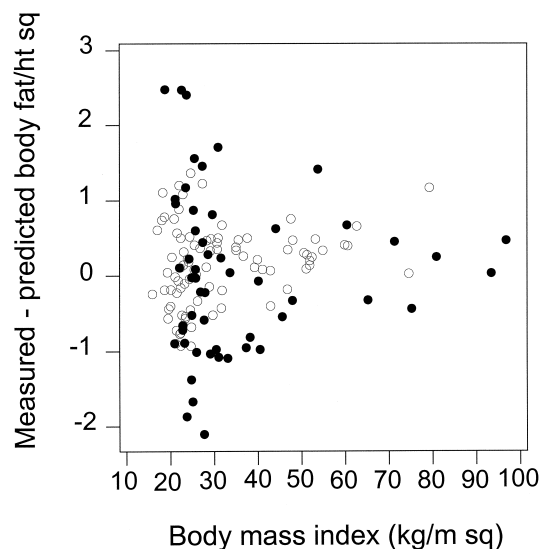


FIG. 3. Plot of the difference between measured and predicted body fat divided by height (m^2) (equations 3 and 4) over the range of body mass index in the study (solid circles, men; open circles, women).

impedance criterion (i.e., had body fat of at least 25% in men and 30% in women). However, 30% of the men and 46% of the women who were not obese by the BMI criterion ($BMI < 30 \text{ kg/m}^2$) actually had obese levels of body fat and therefore would have had their obesity status misclassified based solely on BMI. Thus, BMI alone does not appear to accurately identify all cases of obesity, and this problem is most significant in individuals who may not appear particularly obese (i.e., $BMI < 30 \text{ kg/m}^2$).

Hortobagyi et al.¹⁶ found results similar to ours: for determining obesity, BMI was 55% sensitive and 92% specific in men and 27% sensitive and 98% specific in women. Hydrostatic weighing was used to determine body fat. Although hydrostatic weighing is a valid indicator of body fat, the technique is technically demanding in requiring large, sophisticated, stationary equipment that restricts its use mostly to research settings. Therefore, hydrostatic weighing is not a feasible alternative to BMI in estimating body composition in clinical settings. We used bioelectrical-impedance plethysmography and reached conclusions similar to those of Hortobagyi et al. about the suitability of BMI in the care of obesity. Bioelectrical impedance is a technically simple procedure that is portable and relatively inexpensive and thus a feasible replacement of BMI for determining the presence of obesity in the clinical arena.⁸

Predicting Percentage of Body Fat from the Body Mass Index

In the current study, an attempt was made to use the BMI to develop a predictive equation for the percentage of body fat (equations 1 and 2). However, the quadratic relation between BMI and percentage of body fat and the random variability in the relation created a significant error in predicting percentage of body fat from a regression equation using BMI as the dependent variable (Fig. 2). Variability in the difference between measured and predicted percentage of body fat appeared to be greater in subjects with a BMI below 30 kg/m^2 , as shown in Figure 2, and by lower coefficients of determination in the group of subjects with a BMI of at least 30 kg/m^2 .

Predicting Body Fat/Height² from the Body Mass Index

Because of a relatively low coefficient of determination between BMI and percentage of body fat, use of the BMI predictor of adiposity has been criticized.⁸⁻¹⁰ Garrow and Webster¹¹ and Van Italie et al.¹² argued that BMI is more appropriately an index of total body fat or body fat relative to height rather than body fat relative to mass. Our data generally support the concept of body fat/height² over percentage of body fat as a measure of obesity. In contrast to the quadratic relation between BMI and percentage of body fat, the relation between BMI and body fat/height² in our study was linear (Fig. 1), with a nearly perfect association ($r^2 = 0.99$). (This high degree of correlation was not due to the commonality of height between body fat/height² and body mass/height². The r^2 of body fat mass to total body mass was also 0.99.)

Thus, degree of adiposity appears to be somewhat predictable from BMI, at least on a population scale, if adiposity is defined as an excess of body fat per unit of body height, but not as an excess of body fat per unit of body mass. Like the prediction of the percentage of body fat from the BMI, the prediction of body fat/height² from the BMI is more variable in people with a BMI below 30 kg/m^2 (Fig. 3). However, the differences between measured and predicted body fat/height² seem less severe than the differences between measured and predicted percentage of body fat (Fig. 2). The body fat/height² equation deserves further study as an epidemiologic and clinical tool for defining and tracking obesity and has been suggested as an important tool in determining the existence of protein-energy undernutrition.¹²

Limitations

The question arises as to whether the inability of the BMI to predict body fat is inherent in the use of relative-weight indices in this manner or the result of technical or mathematical errors in the technique we used to measure body fat (bioelectrical impedance). For instance, body mass is a variable common to both BMI and impedance measures of body fat. Validation studies of bioelectrical impedance generally show a strong correlation with other body-composition methods such as hydrostatic weighing and isotope dilution, but with a small systematic underestimation of body fat.¹⁷ If such an error occurred in our study, it would have masked our results (i.e., underestimation of body fat would tend to classify people as leaner than they actually were). However, to answer possible concerns about the use of bioelectrical impedance as the standard for body-composition analysis in the current study, we applied the impedance-derived body-fat-prediction equations from our data to an independent sample of subjects whose body fat was determined by hydrostatic weighing^{18,19} (Appendix). Our impedance-derived prediction equations were capable of predicting body fat in this independent sample without significant systematic error and with an r^2 of 0.91 in men and 0.95 in women. Therefore, we accept the use of bioelectrical impedance in the manner of the current study.

The current study addresses the relation between BMI and body composition in whites but not in other racial groups. Body composition at a given BMI is known to differ across racial groups,^{20,21} and although the general conclusions of this study probably apply to non-whites, the exact relation between BMI and body fat probably does not.

SUMMARY

With impedance-derived body fat as the criterion method, obesity can be confidently presumed at a BMI of at least 30 kg/m^2 . However, obesity levels of body fat commonly occur below this threshold, and BMI alone cannot detect it. Body composition in individuals is difficult to predict accurately from BMI alone, but this is less true for body fat/height² than for percentage of body fat. Indexing body fat to body height may be more appropriate than indexing body fat to body mass, but measurement of body fat may be the preferable method for precise determination of adiposity.

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APPENDIX

The purpose of this appendix is to demonstrate the ability of the bioelectrical-impedance technique used in the current study to determine body fat accurately. Owen et al. published two studies reporting body composition results for 60 individual men and 31 individual women.^{18,19} A calculation of BMI was common to both our data and those of Owen et al., with body fat measured by hydrostatic weighing in those studies versus bioelectrical impedance in ours. We first calculated from our own impedance-data regression equations to predict body fat from BMI:

$$\text{impedance in men: body fat (kg)} = -32.8 + 2.03 (\text{BMI}) \quad (5)$$

$$\text{impedance in women: body fat (kg)} = -22.3 + 1.82 (\text{BMI}) \quad (6)$$

Using the regression equations with the common variable BMI developed from our impedance data, we tried to predict the body-

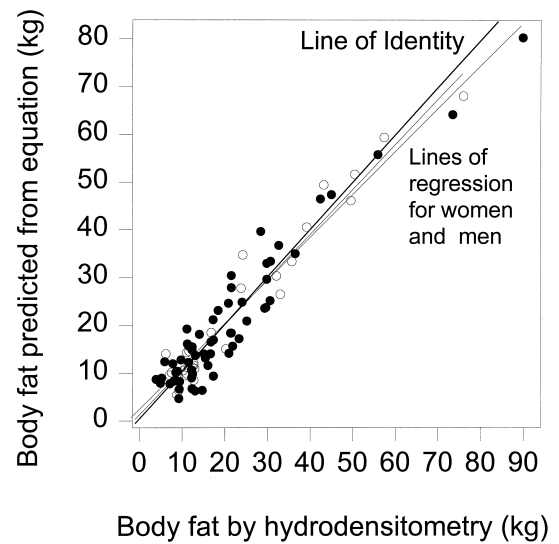


FIG. 4. Predicted body fat in men and women calculated from the body mass index with equations developed in the current study using bioelectrical impedance versus actual body fat in an independent sample of male subjects whose body fat was determined by hydrostatic weighing^{15,16} (solid circles, men; open circles, women).

fat mass of the subjects in the studies by Owen et al. whose body fat was measured with hydrostatic weighing. Graphs of the predicted body fat and measured body fat in their subjects are shown in Figure 4. As can be seen, the line of identity between predicted and actual body fat is nearly the same as the regression line relating these two quantities. If a systematic error existed in our impedance data, we would expect to find a difference in slope or y intercept between the regression line and the line of identity shown in Figure 4. That no difference occurred is evidence that the impedance method accurately assesses body composition and that the use of bioelectrical impedance in our study is appropriate.

(For an additional perspective, see Editorial Opinions)