Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status\textsuperscript{1,2}

Theodore B VanItallie, Mei-Uih Yang, Steven B Heymsfield, Robert C Funk, and Richard A Boileau

ABSTRACT  Expressing fat-free mass (FFM) and body fat mass (BFM) as percentages of body weight or by weight is unsatisfactory. For example, tall patients with protein-energy malnutrition (PEM) can exhibit values for FFM and BFM similar to those of shorter well-nourished individuals. To obviate such difficulties, we propose use of height-normalized indices, namely, a FFM index \[ \text{FFMI} = \frac{\text{FFM (kg)}}{\text{ht (m)}^2}, \] or FFMI, and a BFM index \[ \text{BFMI} = \frac{\text{BFM (kg)}}{\text{ht (m)}^2}, \] or BFMI. We calculated these indices in a reference population of 124 healthy young men and in 32 nonobese young men (from the Minnesota Study) before, during, and after experimental semistarvation. When values for FFMI and BFMI falling below the reference cohort's 5th percentile cutoff point were used as a criterion for PEM, these indices, together with basal oxygen-consumption rate, diagnosed PEM in 27 of the 32 Minnesota Study subjects after 12 wk of semistarvation. These findings indicate that FFMI and BFMI may be useful in nutritional assessment.

KEY WORDS  Fat-free mass, fat-free-mass index, body fat mass, body-fat-mass index, body composition, nutritional assessment, height-normalized indices

Introduction

Recently, two electrical methods, total body electrical conductivity (TOBEC) measurement and bioelectrical impedance analysis (BIA), were found capable of estimating fat-free mass (FFM) and body fat mass (BFM) in patients rapidly and conveniently (1). The resulting opportunity for measurement of these two body constituents on a much larger scale calls for a reassessment of their clinical usefulness. However, appraisal of their utility requires that the information provided about an individual's body composition be expressed in terms that are both meaningful and clinically relevant. Unfortunately, the current practice of reporting FFM and BFM as percentages of body weight or as absolute weights (in kilograms or pounds) does not adequately meet these criteria. In this paper we propose an alternative method for presenting body composition information that we believe will prove to be both more valid and more useful than are the approaches currently used.

An example of the kind of problem associated with reporting FFM and/or BFM as percentages of total body weight or as absolute weights is given in Figure 1. The figure shows that when FFM and BFM are expressed as percentages of total body weight or as absolute weights, a healthy and well-nourished young man can have values for these constituents that are virtually the same as those of a similarly aged but taller individual who suffers from protein-energy malnutrition (PEM).

One potentially useful way to escape from the difficulties in interpreting data introduced by expressing FFM and BFM as absolute values or as percentages of total body weight is to describe these components in terms of kilograms normalized for height. At the very least, use of such indices would simplify the task of interpreting the clinical significance of values for FFM and BFM in individuals of differing heights.

The two indices we believe would help to overcome problems of the kinds illustrated in Figure 1 can be called the fat-free-mass index (FFMI) and the body-fat-mass index (BFMI). Patterned after the body mass index \[ \text{BMI} = \frac{\text{wt (kg)}}{\text{ht (m)}^2} \] (3–5), the two suggested height-normalized indices are calculated as follows:

\[ \text{FFMI} = \frac{\text{FFM (kg)}}{\text{ht (m)}^2}, \]

and

\[ \text{BFMI} = \frac{\text{BFM (kg)}}{\text{ht (m)}^2}. \]

In this paper we attempt to demonstrate the clinical value of the FFMI and the BFMI by showing how these two indices can be helpful in the nutritional assessment of patients. To this end we first compiled an illustrative database of FFMI and BFMI derived from measurement of body composition in a population of healthy adult males grouped by age range. Databases of this kind permit one to identify the percentile segment into which a given patient's FFMI and/or BFMI falls.

Next, we used body composition and basal oxygen-consumption data collected by Keys et al (2) on male volunteer subjects who participated in a carefully controlled study of experimentally induced semistarvation (the Minnesota Study) to test the hypothesis that FFMI and BFMI can be usefully employed to diagnose and monitor the course of semistarvation-induced PEM.

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of experimental semistarvation on these indices. To this end we
drew on data compiled by Keys et al (2) on a group of young
male conscientious objectors who participated in the monu-
mental Minnesota Study of semistarvation during World War
II. In this experiment, 32 healthy and nonobese young men aged
20–33 y were kept on diets providing ~50% of the calories
needed to maintain their weight at baseline levels. The average
energy requirement for weight maintenance was ~14.7 MJ/d
(3500 kcal/d) and the semistarvation diet provided on the average
6.6 MJ/d (1570 kcal/d). The semistarvation part of the exper-
iment lasted for 24 wk, during which the experimenters attempted
to persuade the subjects to adhere to a regime designed to keep
their daily physical activity level as nearly constant as possible.
However, as the subjects became increasingly debilitated, their
willfulness and ability to exercise progressively diminished.

The experimental semistarvation diet was based on food items
commonly used in Europe in times of famine, consisting mainly
of potatoes, turnips, and coarse cereals, with only minute
amounts of meats and dairy products. The total daily intake of
meat, fish, cheese, and eggs combined averaged 29.4 g.

On this diet, the subjects lost an average of 12.1 kg during the
first 12 wk of caloric restriction and 16.8 kg over the entire 24-
wk semistarvation period. At the end of 6 mo of semistarvation,
average weight loss was 24% of initial body weight.

Body composition was determined by hydrodensitometry in
all 32 subjects during a 12-d baseline period, after 12 and 24 wk
of semistarvation, and after 12 wk of refeeding. The subjects' 
body weights and basal oxygen consumption were measured at
the same time. From these data we calculated BMI, FFMI, BFMI,
and basal oxygen consumption (mL·min⁻¹·kg FFM⁻¹) before
and during caloric restriction and after refeeding. The means
and SDs for these indices together with their ranges are given in
Table 2. Statistical analysis of the differences between the means
at various stages of the study was carried out by use of repeated
one-way analysis of variance (9) and the results are shown in
Table 2.

Results

In Figure 2 the means (±SD) and individual values for the
FFMIs of the Minnesota subjects are plotted for the baseline
period (BL), after 12 and 24 wk of semistarvation, and after 12 wk of refeeding (R12). The dashed horizontal

**FIG 1.** Similar values for body weight and body components (expressed as kg and % body wt) of two male participants in the Minnesota Study (2) who differed widely in nutritional status.

**Methods**

*Applied to reference population*

FFM and BFMI were estimated from TOBEC measurements
performed on 192 healthy men aged 20–59 y living in Urbana,
IL. Values for TOBEC were obtained by means of an electro-
magnetic scanning instrument (EM-SCAN, model HA-2,
Springfield, IL) that determines the conductive (fat-free) mass
of the recumbent human body in ~90 s (6). Because conductive
mass is directly proportional to FFM, values for FFM and BFMI
can be readily calculated from TOBEC by the use of appropriate
regression equations based on previously performed validation
studies entailing comparison of TOBEC measurements with hy-
drodensitometric measurements carried out in the same subjects
(7, 8).

FFMI and BFMI were calculated for each subject and the
data were then subdivided according to age range. Percentile
cutoff points (5th, 15th, 50th, 85th, and 95th) were determined
for each index for men in two age categories as shown in Table
1. The values in the table were then used as a tentative basis for
identifying the percentile segment into which the FFMI and/or
BFMI of a given study subject or patient could fall. Indeed, use
of percentiles from a reference population to assess individuals
with suspected malnutrition would not be feasible without the
availability of height-normalized indices of body components
such as FFM and BFMI. We postulated that values below the
5th-percentile cutoff point might reflect substantial depletion
of FFM or BFMI whereas those above the 95th percentile might
indicate substantial excess of FFM or BFMI. Values falling within
the range of the 5th–15th or the 85th–95th percentiles were
thought to suggest the presence of some degree of depletion or
excess, respectively.

*Applied to Minnesota Study subjects*

A logical first step toward testing the usefulness of the FFMI
and BFMI in nutritional assessment was to determine the effect

**Table 1**

<table>
<thead>
<tr>
<th>Percentile cutoff points</th>
<th>5</th>
<th>15</th>
<th>50</th>
<th>85</th>
<th>95</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–39 y (n = 124)</td>
<td>16.8</td>
<td>17.7</td>
<td>19.9</td>
<td>22.2</td>
<td>25.8</td>
</tr>
<tr>
<td>40–59 y (n = 68)</td>
<td>17.4</td>
<td>19.9</td>
<td>19.2</td>
<td>20.9</td>
<td>22.4</td>
</tr>
<tr>
<td>BFMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20–39 y (n = 124)</td>
<td>2.4</td>
<td>2.8</td>
<td>4.3</td>
<td>6.8</td>
<td>8.3</td>
</tr>
<tr>
<td>40–59 y (n = 68)</td>
<td>1.5</td>
<td>4.4</td>
<td>6.3</td>
<td>8.1</td>
<td>9.7</td>
</tr>
</tbody>
</table>

* Fat-free mass and body fat mass were determined by means of an
electromagnetic scanning instrument.
TABLE 2
Values for various indices of nutritional status at baseline (BL), after 12 and 24 wk of semistarvation (S12 and S24), and after 12 wk of refeeding (R12) in the Minnesota Study subjects

<table>
<thead>
<tr>
<th>Index</th>
<th>BL</th>
<th>S12</th>
<th>S24</th>
<th>R12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass index (BMI)</td>
<td>21.7 ± 1.7*</td>
<td>17.9 ± 1.2a</td>
<td>16.4 ± 0.9c</td>
<td>18.4 ± 1.2d</td>
</tr>
<tr>
<td></td>
<td>(18.4-25.4)</td>
<td>(16.0-20.3)</td>
<td>(14.9-18.6)</td>
<td>(15.6-20.7)</td>
</tr>
<tr>
<td>FFMI</td>
<td>18.7 ± 1.5*</td>
<td>16.5 ± 1.3b</td>
<td>15.5 ± 1.1c</td>
<td>16.4 ± 1.2p</td>
</tr>
<tr>
<td></td>
<td>(14.6-21.8)</td>
<td>(13.6-19.1)</td>
<td>(12.4-17.9)</td>
<td>(13.5-19.1)</td>
</tr>
<tr>
<td>BFMI</td>
<td>3.1 ± 1.2*</td>
<td>1.4 ± 1.0b</td>
<td>0.9 ± 0.7c</td>
<td>2.0 ± 0.9d</td>
</tr>
<tr>
<td></td>
<td>(1.5-6.1)</td>
<td>(0.0-4.3)</td>
<td>(0.0-3.4)</td>
<td>(0.0-4.4)</td>
</tr>
<tr>
<td>Basal oxygen consumption</td>
<td>3.8 ± 0.2a</td>
<td>3.0 ± 0.3d</td>
<td>2.8 ± 0.3c</td>
<td>3.5 ± 0.4d</td>
</tr>
<tr>
<td>(mL · min⁻¹ · kg FFM⁻¹)</td>
<td>(3.4-4.2)</td>
<td>(2.3-3.7)</td>
<td>(2.3-3.7)</td>
<td>(2.6-4.2)</td>
</tr>
</tbody>
</table>

* x ± SD; n = 32; range in parentheses. Adapted from data reported by Keys et al (2).
Values with different letter superscripts within a row are significantly different, P < 0.02 (repeated one-way analysis of variance).

FIG 2. Fat-free-mass indices (x ± SD) together with the individual values of the Minnesota Study subjects at baseline (BL), after 12 and 24 wk of semistarvation (S12 and S24), and after 12 wk of refeeding (R12). Dashed horizontal lines represent percentile cutoff points derived from body composition measurements in 124 healthy males aged 20–39 y (Urbana reference population).

FIG 3. Body-fat-mass indices (x ± SD) together with the individual values of the Minnesota Study subjects at baseline (BL), after 12 and 24 wk of semistarvation (S12 and S24), and after 12 wk of refeeding (R12). Dashed horizontal lines represent percentile cutoff points derived from body composition measurements in 124 healthy males aged 20–39 y (Urbana reference population).

Discussion
The case for height-normalized indices of body composition

Just as BMI is useful in evaluating the body weights of individuals of different heights, so are the FFMI and the BFMI po-
The centiles changes in nutritional status. The same indices can also be used to help monitor subsequent 25% of subjects who exhibited BL FFMIs below the 15th percentile cutoff point of 17.7 of the Urbana cohort aged 20–39 y. In the diagnosis of PEM at BL had FFMI > 2.7. In one instance (subject 129) the BFMI was 1.7 (fat content being 9.3% of body weight). However, like all eight subjects with low FFMI values at BL, subject 129 had a basal oxygen consumption well within the BL range. This observation suggests that the subject could have been in the process of recovering from an earlier bout of PEM (see next section on effect of refeeding).

Second, to avoid falsely diagnosing the absence of PEM in the 16% of subjects who at S12 had FFMI above the 15th percentile, it is once again helpful to look at the BFMI shown in Table 4. In every case, BFMI was < 1.4 at S12. In addition, at S12 none of these subjects exhibited a basal oxygen-consumption rate > 3.0 mL · min⁻¹ · kg FFM⁻¹.

An indication of the diagnostic power, as applied to the Minnesota cohort, of the three indices (FFMI, BFMI, and FFMI-normalized basal oxygen consumption), whether used individually or in combination, can be obtained from Table 5. This table shows the extent to which each of the 32 Minnesota subjects, listed by identification number, meets three proposed criteria for diagnosing PEM at S12, namely, an FFMI below the 5th percentile, a BFMI below the 5th percentile, and a basal oxygen uptake < 3.4 mL · min⁻¹ · kg FFM⁻¹ (representing the lowest value observed during the BL period).

### Table 3

<table>
<thead>
<tr>
<th>Subject</th>
<th>FFMI</th>
<th>BFMI</th>
<th>After 12 wk semistarvation</th>
</tr>
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<tbody>
<tr>
<td>119</td>
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<tr>
<td>11</td>
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<td>101</td>
<td>16.8</td>
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BFMI * Basal oxygen-consumption rate.

BFMI. With one exception, all of the subjects with a low FFMI at BL had BFMI > 2.7. In one instance (subject 129) the BFMI was 1.7 (fat content being 9.3% of body weight). However, like all eight subjects with low FFMI values at BL, subject 129 had a basal oxygen consumption well within the BL range. This observation suggests that the subject could have been in the process of recovering from an earlier bout of PEM (see next section on effect of refeeding).

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An indication of the diagnostic power, as applied to the Minnesota cohort, of the three indices (FFMI, BFMI, and FFMI-normalized basal oxygen consumption), whether used individually or in combination, can be obtained from Table 5. This table shows the extent to which each of the 32 Minnesota subjects, listed by identification number, meets three proposed criteria for diagnosing PEM at S12, namely, an FFMI below the 5th percentile, a BFMI below the 5th percentile, and a basal oxygen uptake < 3.4 mL · min⁻¹ · kg FFM⁻¹ (representing the lowest value observed during the BL period).

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</table>
As shown in Table 5, after 12 wk of semistarvation, 14 subjects met all three criteria, 13 met two of the three, and 4 met one of the three. One subject (subject 5) failed to meet any of the criteria. Thus, when these relatively stringent criteria were employed, 27 of 32 subjects (84%) fulfilled at least two of the three criteria. Interestingly, the four subjects who met only one of the three criteria (subjects 119, 120, 126, and 109) and the single subject who met none of them (subject 5) were among the fattest members of the Minnesota cohort during the BL period. This fact presumably accounts for the failure of subjects 119, 120, 5, and 109 to reduce BFMI to a point below the 5th percentile at S12. It is noteworthy that during the BL period, none of the subjects had both an FFMI and a BFMI below the 5th percentile.

Interpretation of data from malnourished patients during refeeding phase

It is interesting that after 12 wk of refeeding, mean FFMI increased only slightly, rising from 15.5 ± 1.1 at S24 to 16.4 ± 1.2 at R12. Thus, mean FFMI at R12 is virtually identical with the value of 16.5 ± 1.3 determined at S12. As indicated in Table 2, mean BFMI rises more steeply than FFMI during refeeding, increasing from 0.9 ± 0.7 at S24 to 2.0 ± 0.9 at R12. Even more striking is the increase in basal oxygen consumption rate that occurs during refeeding. Indeed, it appears that oxygen-consumption rate is the most responsive of the three indices to refeeding. As shown in Table 2, basal oxygen-consumption rate rises from a mean of 2.8 ± 0.3 at S24 to 3.5 ± 0.4 mL·min⁻¹·kg FFM⁻¹ at R12. Thus, mean basal oxygen-consumption rate at R12 is well above the 3.0 ± 0.3 mL·min⁻¹·kg FFM⁻¹ observed at S12.

The dissociation between FFMI and BFMI that occurs during the refeeding of individuals with PEM can confound interpretation of FFMI and BFMI values. Moreover, during refeeding, the dissociation that develops between a low BFMI and a basal oxygen-consumption rate close to the BL level could be even more confusing. To deal with the metabolic discrepancies observed in patients recovering from PEM, one has to rely first of all on a history of weight loss (associated with voluntary or illness-induced energy-protein deficit), followed by an increased food intake and recent weight regain. In any case, when a patient exhibits an FFMI below the 15th percentile, together with a normal or marginal BFMI and a normal or marginal basal oxygen-consumption rate, one has to consider the possibility that the individual in question is in the process of recovering from PEM.

Relevance of the Minnesota cohort

To establish the presence of PEM it is very helpful to have subjects whose recent nutritional history is well known and whose nutritional status is not confounded by the presence of one or more complicating illnesses. In this sense, the Minnesota cohort constituted an almost ideal subject population. The subjects' PEM was induced experimentally by creating a well-controlled chronic calorie deficit. Moreover, the Minnesota subjects were healthy before caloric restriction and for the most part did not suffer from significant complicating illnesses during the semistarvation and refeeding periods.

Despite these clear advantages, the Minnesota subjects, being normal-weight Caucasian males aged 20–33 y, are representative of only a fraction of the population of patients encountered by physicians in the course of their practice. Moreover, there are many variants of PEM, depending on the nature of the cause (or causes) and the preexisting nutritional status of the individual. Specifically, FFM and BFMI may have been depleted in varying proportions and edema may or may not be present. Nevertheless, because of the carefully controlled nature of the experiment in which they participated, the Minnesota subjects are well suited to demonstrate the potential diagnostic value of such indices as the FFMI, the BFMI, and the basal oxygen-consumption rate.

Data from the Minnesota Study show that FFMI and BFMI are inherently more accurate than FFMI and BFMI (expressed in terms of absolute weight or percentage of body weight) as indicators of nutritional status. As the Minnesota subjects developed increasingly severe PEM, FFMI (as a percentage of body weight) paradoxically increased (Fig 5). Together, FFMI and BFMI constitute 100% of body weight. Therefore, if one of the components decreases more than the other, the other will exhibit a relative increase.

BFMI (expressed as a percentage of body weight) decreased as expected during semistarvation; however (as shown in the lower
Among the 32 Minnesota subjects (white males aged 20–33 y) BL BMIs were 23.0 at the 75th percentile, 21.9 at the 50th, and 20.6 at the 25th. In view of these relatively low BMIs and because BMI equals FFMI plus BFMI, it is not surprising that the BMI itself is a good indicator of the presence and severity of PEM in the Minnesota subjects. However, because the BMI can vary widely depending on body fat content, it cannot serve as a reliable indicator of PEM in individuals whose fat stores were relatively large before the development of PEM. For example, 7 of 17 obese dieters who died of ventricular arrhythmias in association with presumptive myocardial protein depletion after prolonged adherence to a very-low-calorie diet consisting of poor-quality protein were still 20% over desirable BMI when they died (11). And as pointed out by Shizgal et al (12) and Rasmussen and Andersen (13), body fat may remain normal or even excessive in spite of the development of moderate to severe PEM. Furthermore, FFMI, normalized for height, can serve as a key indicator of protein nutriture. Therefore, it would seem essential to measure this component directly whenever possible, rather than infer its status from the BMI, anthropometric data, or other less specific indicators.

Excess hydration during semistarvation

As semistarvation progressed, the Minnesota subjects retained increasing amounts of extracellular water (ECW). From measurements of the thiocyanate space in a subset of the Minnesota cohort, Keys et al (2) estimated that an average of 3.5 L had accumulated by S12. Overhydration of the LBM increased total body specific gravity in the Minnesota subjects; thus, loss of the lean tissue component of the FFMI at S12 was underestimated by ~1.24 kg. At the same time, fat loss was overestimated by ~0.83 kg. This observation serves as a reminder that in patients with PEM accompanied by expansion of the ECW, actual depletion of lean tissue will be somewhat greater, not less, than that inferred from hydrodensitometry or TOBEC (1). The slight underestimation of lean tissue loss obtained with FFMI values uncorrected for excess ECW did not affect the diagnostic power of this index at S12. The overestimation of the fat loss that had occurred by S12 was also relatively small and did not compromise the usefulness of the BFMI in the diagnosis of PEM in the Minnesota cohort.

Summary

We proposed the use of height-normalized indices for FFMI and BFMI to avoid the ambiguities frequently generated when these components are reported as percentages of body weight and/or by absolute weight. In addition, analysis of data compiled in the Minnesota Study indicates that FFMI and BFMI, particularly in concert with oxygen-consumption rate, are useful indices to assess patients suspected of having PEM. Although a low BMI may also suggest the presence of PEM, particularly in previously nonobese individuals who have experienced substantial weight loss, the BMI alone cannot provide information about the status of the FFMI vs the status of the BFMI in such people, nor can sequential BMIs delineate the relative contribution of fat loss and LBM loss to a progressive decline in weight. Moreover, BMI alone is unable to alert the physician to the presence of protein malnutrition in previously obese patients who have lost weight very rapidly but whose BMI remains within the normal range. Finally, a low BMI, such as that frequently exhibited by athletes or asthenic individuals, is not necessarily indicative.

One fact about the Minnesota cohort requires special emphasis. Before their participation in the semistarvation experiment, these subjects were slightly underweight compared with current national averages. Thus, for example, the BMIs of a national probability sample of white males aged 20–29 y examined during the second National Health and Nutrition Examination Survey (NHANES II [1976–80]) were 26.3 at the 75th percentile, 23.8 at the 50th, and 21.8 at the 25th (10).

As pointed out earlier, one can speculate that, because of their relatively high content of body fat before caloric restriction, the five subjects who were not unequivocally diagnosed as having PEM may, in fact, have been less severely affected by this disorder than their initially leaner fellow experimental subjects.

When the same criteria used to diagnose PEM at S12 were applied to the subjects’ FFMI, BFMI, and basal oxygen-consumption rates at BL, there were no false positives.

**BMI vs FFMI and BFMI**

Comparison of height-normalized indices (Δ) for fat-free mass (FFMI) and body fat mass (BFMI) with means for fat-free mass (FFM) and body fat mass (BFM) expressed as percentages of body weight (%BWt) in the Minnesota cohort at baseline (BL), during semistarvation (S12 and S24), and after 12 wk of refeeding (R12).
of malnutrition. In contrast to these inadequacies of the BMI, the FFMI and BFMI used in conjunction with a percentile grid derived from a suitable reference population can be expected to provide more meaningful information about nutritional status.

In this paper the reference population of healthy men used to derive percentile cutoff points to serve as criteria for the presence or absence of PEM was illustrative only. The FFMI and BFMI norms presented in Table 1 are provisional and will require modification once data on a much larger and more representative population become available.

References