Adjusting body cell mass for size in women of differing nutritional status\textsuperscript{1–3}

Jonathan CK Wells, Alexia J Murphy, Helen M Buntain, Ristan M Greer, Geoffrey J Cleghorn, and Peter SW Davies

ABSTRACT

Background: Body cell mass (BCM) may be estimated in clinical practice to assess functional nutritional status, eg, in patients with anorexia nervosa. Interpretation of the data, especially in younger patients who are still growing, requires appropriate adjustment for size. Previous investigations of this general issue have addressed chemical rather than functional components of body composition and have not considered patients at the extremes of nutritional status, in whom the ability to make longitudinal comparisons is of particular importance.

Objective: Our objective was to determine the power by which height should be raised to adjust BCM for height in women of differing nutritional status.

Design: BCM was estimated by \textsuperscript{40}K counting in 58 healthy women, 33 healthy female adolescents, and 75 female adolescents with anorexia nervosa. The relation between BCM and height was explored in each group by using log-log regression analysis.

Results: The powers by which height should be raised to adjust BCM were 1.73, 1.73, and 2.07 in the women, healthy female adolescents, and anorexic female adolescents, respectively. A simplified version of the index, BCM/height\textsuperscript{2}, was appropriate for all 3 categories and was negligibly correlated with height.

Conclusions: In normal-weight women, the relation between height and BCM is consistent with that reported previously between height and fat-free mass. Although the consistency of the relation between BCM and fat-free mass decreases with increasing weight loss, the relation between height and BCM is not significantly different between normal-weight and underweight women. The index BCM/height\textsuperscript{2} is easy to calculate and applicable to both healthy and underweight women. This index may be higher than 2 (2). The 2 indexes FFM/height\textsuperscript{2} and FM/height\textsuperscript{2} provide an important means for assessing fatness and relative lean size independently.

To interpret body-composition data, it is preferable to adjust for body size. Both fat and fat-free components of weight vary in relation to body size, and such variability should be taken into account in evaluating a person’s phenotype. This is particularly important in children and adolescents, who may grow in size over the duration of a weight-loss or refeeding intervention. Body fat has traditionally been adjusted by dividing by weight to calculate percentage fat, although this approach is inappropriate and can be misleading (1, 2). Fat-free mass (FFM) tends not to be adjusted for size. For both components of weight, it is more appropriate to adjust for an index of body size that is not expressed as a mass, ie, height (3).

The relation between weight and height has been explored in detail for more than a century (4). Weight can be adjusted for height by using the index weight/height\textsuperscript{p}, where the power of p is close to 2 for almost the entire human life span (5). Thus weight/height\textsuperscript{2}, or body mass index (BMI; in kg/m\textsuperscript{2}), is widely used as an index of nutritional status in adults and children (6, 7). The 2 chemical components of weight, FFM and fat mass (FM), can also be adjusted by using the same approach. Because weight = FFM + FM, the simplest approach is to divide BMI into 2 indexes, ie, FFM/height\textsuperscript{2} and FM/height\textsuperscript{2} (3). However, more detailed analyses indicate that the optimal power of p for FM/height\textsuperscript{p} may be higher than 2 (2). The 2 indexes FFM/height\textsuperscript{p} and FM/height\textsuperscript{p} provide an important means for assessing fatness and relative lean size independently.

Body cell mass (BCM) is an important component of FFM, and the measurement of BCM represents one approach for estimating skeletal muscle mass (8, 9) or FFM (10, 11). However, during malnutrition, not all components of FFM are lost in equal proportion. Skeletal mass and connective tissue are relatively preserved during starvation, whereas BCM decreases. For clinical evaluations of recovery from malnutrition, repeated measurements of BCM may therefore be more informative than are

KEY WORDS Body composition, potassium counting, eating disorders, anorexia nervosa

INTRODUCTION

Improved access to measurement facilities, combined with increasing sophistication of methodologic techniques, has led to an increase in the measurement of body composition in clinical practice. Measurement of body composition may be undertaken to assess both energy stores (fatness) and functional tissues (various components of lean mass). Examples include evaluations of weight-loss programs in obese subjects, evaluations of refeeding programs in undernourished subjects, and monitoring of bone mineralization during hormone replacement therapy.

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iodide detectors were calibrated fortnightly by using sources of potassium chloride phantom containing 180 g K. The sodium activity of the TBK counter was also assessed daily by using a adjusted for these background and sensitivity values. The accuracy of the phantom were found to change by 0.5% over the past 4 y. Background counts were measured nightly over an 8-h period, and sensitivity was ranged widely in BMI, whereas the anorexic female adolescents had significantly lower BCM for their height. The results of multiple regression analysis 3 cm). The women averaged 26.6 y of age, whereas both the healthy and the anorexic female adolescents averaged 14.8 y of age. The healthy women ranged widely in BMI, whereas the anorexic female adolescents had a mean (± SD) BMI of 16.4 ± 1.6, and most of them (89%) had BMI values that were significantly lower than the chronic energy deficiency cutoff of 18.5/14 (P < 0.0001). The healthy women and the healthy female adolescents did not differ significantly in height or BCM. However, the healthy female adolescents were significantly shorter (2 cm) than the healthy women with anorexia (P < 0.005), who had markedly lower weight and BCM (P < 0.001).

The relation between log BCM and log height is shown in Figure 1. The relation was not significantly different between the healthy women and the healthy female adolescents, whereas the female adolescents with anorexia had consistently lower BCM for their height. The results of multiple regression analysis are given in Table 2. Compared with the healthy women, the anorexic female adolescents, but not the healthy female adolescents, had significantly lower BCM for their height.

The results of the regression of log BCM on log height in each group are given in Table 3. The values of p were 1.73, 1.73, and 2.07 for the women, healthy female adolescents, and anorexic female adolescents, respectively. The closest whole number to

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Description of the sample†</th>
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<tbody>
<tr>
<td></td>
<td>Healthy women (n = 58)</td>
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<tr>
<td>Age (y)</td>
<td>26.6 ± 5.7 (20.1–39.9)</td>
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<tr>
<td>Weight (kg)</td>
<td>59.6 ± 11.2 (44.4–113.4)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.66 ± 0.08 (1.50–1.90)</td>
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<tr>
<td>BMI (kg/m²)</td>
<td>21.6 ± 2.5 (17.0–32.8)</td>
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<tr>
<td>BCM (kg)</td>
<td>23.3 ± 3.6 (17.7–37.3)</td>
</tr>
<tr>
<td>BCM index (kg/m²)</td>
<td>8.5 ± 1.1 (6.7–11.5)</td>
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†All values are ± SD; range in parentheses. BCM, body cell mass.
‡Significantly different from healthy women, P < 0.01 (multiple group comparisons with Bonferroni correction).
§Significantly different from healthy women and healthy female adolescents, P < 0.001 (multiple group comparisons with Bonferroni correction).

The repeated measurement of FFM. Because pediatric patients may grow in height while gaining weight, such evaluations require appropriate adjustment of BCM for size. The purpose of the present analysis was to investigate 1) whether in healthy adolescent and adult females, a relation exists between BCM and height that is similar to the relation between FFM and height reported previously; and 2) whether this relation is altered in adolescent females with anorexia nervosa.

SUBJECTS AND METHODS

Data were obtained from a database of clinical measurements carried out at the Royal Children’s Hospital, Brisbane, Australia, over the period 1986–2002. Ethical approval for use of anonymous forms of these data was granted by the ethical committee of the Royal Children’s Hospital.

BCM was estimated with the use of total body potassium (TBK) counting, which was performed by using a shadow shield whole-body counter (Accuscan; Canberra Industries, Meriden, CT), which contains 3 sodium iodide scintillation detectors arranged to give a total detector area of 1200 cm². These detectors are shielded by steel that is 10 cm in depth. Background counts were measured nightly over an 8-h period, and sensitivity was measured daily by using a potassium chloride phantom containing 272 g K. Gross potassium counts for each subject were adjusted for these background and sensitivity values. The accuracy of the TBK counter was also assessed daily by using a potassium chloride phantom containing 180 g K. The 3 sodium iodide detectors were calibrated fortnightly by using sources of 60Co and 137Cs. Overnight background counts were found to change by ≈0.09%/y over an 8-y period, whereas measurements of the phantom were found to change by 0.5% over the past 4 y.

Potassium is the primary intracellular cation, and 98% of the body’s potassium is located within the BCM (12). Because a fixed proportion of potassium occurs as the natural isotope 40K, TBK can be measured by detecting the 1.46-MeV gamma ray emitted by 40K. BCM was calculated by using the equation of Wang et al (13):

BCM (kg) = [TBK (g) × 9.18] / 39.1 (1)

The measurement required the subject to lie supine on a scanning bed that was moved under the detectors. Two 1100-s scans were performed for each subject with all personal metallic objects having been removed. Background and sensitivity checks were completed daily and considered in each measurement. On the basis of repeated measurements of phantoms, the precision of BCM values was 2.3%.

The relation between body composition and size was investigated by using log-log regression analysis. For each category of women, log BCM was regressed on log height by using natural logarithms to the base e, and the gradient p of the regression equation was determined. The index BCM/height⁶ could then be assumed to have zero correlation with height and hence to represent a size-independent index of BCM.

To assess the implications of any residual correlation between BCM/height⁶ and height if the power p was rounded to the closest whole number, correlation analysis was used. Differences in body-composition variables between the 3 groups were assessed by using multiple comparisons between groups with Bonferroni correction. Regression analyses were conducted by using SPSS software version 10 (SPSS Inc, Chicago).

RESULTS

A description of the sample is given in Table 1. The women averaged 26.6 y of age, whereas both the healthy and the anorexic female adolescents averaged 14.8 y of age. The healthy women ranged widely in BMI, whereas the anorexic female adolescents had a mean (± SD) BMI of 16.4 ± 1.6, and most of them (89%) had BMI values that were significantly lower than the chronic energy deficiency cutoff of 18.5/14 (P < 0.0001). The healthy women and the healthy female adolescents did not differ significantly in height or BCM. However, the healthy female adolescents were significantly shorter (2 cm) than the healthy women with anorexia (P < 0.005), who had markedly lower weight and BCM (P < 0.001).

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The results of the regression of log BCM on log height in each group are given in Table 3. The values of p were 1.73, 1.73, and 2.07 for the women, healthy female adolescents, and anorexic female adolescents, respectively. The closest whole number to
which these \( p \) values could be rounded was 2 in each case, which indicates that BCM/height\(^2\) is the optimum index in simplified form. The proportion of variation in BCM/height\(^2\) that could be attributed to height was \(<2\%\) for all 3 groups.

**DISCUSSION**

The results of this study show that the relation between BCM and height in normal-weight females, either adolescents or adults, is similar to that between FFM and height (2, 3). This finding should not be considered surprising: over the healthy range of weight, BCM is a relatively constant proportion of FFM, which allows the prediction of FFM from BCM. However, as the starvation characteristic of anorexia nervosa brings about weight loss, not all components of FFM are lost equally, and with increasing malnourishment, the consistency between BCM and FFM decreases. Nevertheless, our study indicates that this disagreement is not of sufficient magnitude to alter the general relation between body composition and size. Our study shows that the same index, BCM/height\(^2\), is appropriate for both healthy and malnourished females. This finding implies that a relatively simple adjustment of BCM for size can be used in clinical practice to interpret the effects of refeeding on nutritional status independently of those on size.

All the regression equations determined in our analyses gave values for \( p \) that were close, but not exactly equal, to 2. However, we showed that for each group of females, the proportion of variability in BCM/height\(^2\) that was due to height was negligible (\(<2\%\)). Thus, there is nothing to be gained by using the specific power values described in Table 3, and the index BCM/height\(^2\) may be considered satisfactory.

The past decade has seen rapid progress in our ability to express data on size, growth, nutritional status, and body composition so as to address clinically important research questions. Examples include new charts to assess changes in BMI with age (6), the expression of data as SD scores to control for variation in age and sex (6, 15), and the ability to evaluate growth rate in

**TABLE 2**

<table>
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<th>Results of multiple linear regression analysis of log body cell mass for the 3 groups of females</th>
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<td>Coefficient</td>
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<td>---------------------------------</td>
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<tr>
<td>Healthy women (n = 58)</td>
</tr>
<tr>
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<td>Constant</td>
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<tr>
<td>Log height</td>
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<td>Anorexic female adolescents (n = 75)</td>
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<tr>
<td>Constant</td>
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<td>Log height</td>
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relation to initial size (16) or other variables of growth (17). At the same time, the proliferation of new charts and indexes may be confusing for health professionals. One study reported a high degree of error in calculating indexes of children’s weight relative to height (18), and there is also confusion as to which of several indexes is most appropriate (19). Only if indexes and charts can be presented in a format that is readily understandable are they likely to be widely adopted in clinical practice and contribute to routine clinical care.

The BCM/height index that we propose in the present study is similar in format to BMI and to the equivalent indexes the FFM index and the FM index (3). Taken together, our results and those of other researchers indicate that in most scenarios, the adjustment of weight, FFM, BCM, or fat for height is satisfactorily achieved by dividing by the square of height. The one exception to this general finding is that when comparing fatness between children who differ widely in height, the FM index may not represent a satisfactory adjustment because it fails to adjust fully for variability in height (2). Although the FM index can be used to acceptably rank children in terms of fatness at a given time point, the index may not be appropriate for investigations of change in fatness over time.

In the present study, the difference in height between the adolescent females with or without anorexia was significant but relatively modest. However, anorexia nervosa is primarily a condition of adolescents, and its early onset is associated with delayed entry into puberty (20) and hence delayed growth in height (21). We also showed previously that in younger children, anorexia leads to substantial loss of FFM (22). During refeeding, weight gain may be accompanied by rapid growth in height; thus, the interpretation of changes in body composition without simultaneous adjustment for changes in height is problematic.

Our study shows that, as with other components of body mass, BCM can be satisfactorily adjusted for size by dividing by the square of height in both normal-weight and malnourished females. This approach is conceptually relatively simple and should be easy to incorporate into practice. Our study improves the ability to assess improvements in nutritional status independently of changes in height in young anorexic females undergoing refeeding programs.

JCKW conceived and conducted the analysis and wrote the first draft of the manuscript. AJM performed a portion of the measurements and contributed to the first draft of the manuscript. HMB was responsible for the recruitment and organization of a portion of the healthy adolescent subjects. RMG was responsible for the recruitment and organization of a portion of the healthy adult subjects. GJC was responsible for overseeing a portion of the measurements. PSWD was responsible for overseeing a portion of the measurements. All authors contributed to the final manuscript. None of the authors had any conflicts of interest.

REFERENCES