Body composition in adolescents with anorexia nervosa

Kate P Kerruish, Janice O’Connor, Ian RJ Humphries, Michael R Kohn, Simon D Clarke, Julie N Briody, Emma J Thomson, Katharine A Wright, Kevin J Gaskin, and Louise A Baur

ABSTRACT

Background: Malnourished patients with anorexia nervosa have altered body composition characterized by depletion of fat and fat-free mass.

Objectives: The objectives of this study were to assess the body composition of adolescents with anorexia nervosa compared with that of control subjects and to investigate the relation between simple anthropometric measures and reference techniques for measuring body composition.

Design: Twenty-three adolescent females with anorexia nervosa aged 15.46 ± 1.34 y (X ± SD) were studied. Body composition was measured by anthropometry, dual-energy X-ray absorptiometry (DXA) (for body fat), and prompt gamma in vivo neutron activation analysis [for total body nitrogen (TBN)]. Twenty-five female subjects provided the control DXA data. TBN measurements were compared with prediction equations based on sex, height, age, and weight.

Results: Anorexia nervosa patients had significantly lower weight (40.2 ± 4.6 kg), body mass index (in kg/m²: 15.3 ± 1.2), percentage of body fat (DXA) (13.8 ± 5.8%), percentage of TBN predicted for age (73 ± 10%), trunk fat (2.1 ± 1.0 kg), leg fat (2.6 ± 1.1 kg), and trunk-to-leg fat ratio than did control subjects (P < 0.05). In anorexia nervosa patients, significant correlations were found between triceps skinfold thickness and percentage of body fat (r = 0.83), body mass index and percentage of body fat (r = 0.46), and body weight and TBN (r = 0.84, P < 0.05).

Conclusions: Hospitalized adolescent females with anorexia nervosa are depleted of total body fat and protein. We identified 3 simple anthropometric measures (triceps skinfold thickness, BMI, and body weight) that can be used to assess body composition and nutritional status in malnourished adolescents with anorexia nervosa. Am J Clin Nutr 2002;75:31–7.

KEY WORDS Anorexia nervosa, adolescents, dual-energy X-ray absorptiometry, prompt gamma in vivo neutron activation analysis, anthropometry, skinfold thicknesses, total body nitrogen, body fat, females

INTRODUCTION

Anorexia nervosa is estimated to be the third most common chronic medical illness in girls aged 15–19 y, affecting ≈0.5% of adolescent girls in Western countries (1). Although eating disorders occur most commonly in adolescents, much of the literature combines findings from adults and adolescents (2, 3) or reports results obtained solely from adults (4–6). However, because of the biological events that occur during adolescence, it is important that adolescents be considered as a separate group.

Adult patients with anorexia nervosa usually have depleted fat stores and reduced body protein (7). Body-composition measurements of skinfold thickness (2, 8–10), body fat mass (2, 8, 11, 12), bone mass (13), body water (3, 8), and body protein (13) have been examined in many studies, that included adolescent anorexia nervosa patients. However, none of the studies that focused on adolescents measured body fat mass by the more widely used method of dual-energy X-ray absorptiometry (DXA), which has been proposed as a precise and suitable tool for body-composition assessment in children and adolescents (14, 15).

To assess protein nutritional status, total body nitrogen (TBN), and hence total body protein, was measured by prompt gamma in vivo neutron activation analysis (NAA) in patients with anorexia nervosa in 2 separate studies, both involving adult and adolescent patients (7, 13). Unfortunately, Kooh et al (13) did not compare these measurements of TBN with the appropriate control reference data for age, height, and weight.

The advantage of using NAA over other techniques for estimating protein nutritional status is that it measures body protein directly and is not affected by other factors such as hydration status, renal function, and catabolism. NAA has been shown to provide safe, accurate, and precise measurements of TBN in children and adolescents (15, 16).

NAA and DXA are both sophisticated tools for measuring body composition, but may not be available in many units. Hence, simpler methods of estimating body composition, such as anthropometry, are often used. However, questions remain regarding the validity of anthropometric measurements for body-composition

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assessments in anorexia nervosa and whether these measurements correlate well with more sophisticated methods, such as DXA and TBN assessment (17). The present study aimed to look exclusively at adolescent girls with anorexia nervosa to determine body composition and describe disease characteristics in the malnourished state, 2) compare body composition with that of a control group, and 3) compare anthropometric measurements with reference measures of body composition (TBN and DXA).

SUBJECTS AND METHODS

Subjects

Twenty-three female adolescents aged 13–18 y with anorexia nervosa were recruited between March 1999 and May 2000 from the Departments of Adolescent Medicine at The Children’s Hospital at Westmead and at Westmead Hospital, both in western Sydney, Australia. All patients met the diagnostic criteria for anorexia nervosa as presented in the 4th edition of the Diagnostic and Statistical Manual (18). Patients were categorized as restricters if they had lost weight through restricting dietary intake or as restricters and purgers if they also engaged in purging activities, such as laxative abuse or self-induced vomiting. Patients were classified as overexercisers if they participated in strenuous exercise for periods of >30 min daily, or exercised specifically as a weight-control measure.

Patients with any metabolic or endocrine disorders that may affect energy metabolism were excluded from the study. No patient had a history of chronic organ disease (eg, diabetes or chronic asthma) or endocrinopathies. Some patients were prescribed medications for depression or electrolyte replacement designed and built the TBN facility used in the present study. The facility is housed at The Children’s Hospital at Westmead. This technique involves the patient being bilaterally irradiated with neutrons from twin 252Cf sources. TBN is calculated by measuring the integral under the nitrogen peak centered at 10.8 MeV on the gamma ray spectrum. This technique has been described in other studies (15, 16). The scan involves a radiation dose of <0.2 mSv and takes ~15 min, during which time the patient lies motionless in the supine position.

Anthropometry

Anthropometry was performed by using standard and calibrated instruments (20). Height (±0.1 cm) was measured in patients who were not wearing shoes by using a Harpenden stadiometer (Holtain Ltd, Crosswell, United Kingdom). Weight (±0.1 kg) was measured by using electronic scales with the patient wearing light clothing. Body mass index (BMI; in kg/m²) was calculated as body weight/height². Height, weight, and BMI measurements were compared with the National Center for Health Statistics reference values for age and sex (21, 22).

Skinfold thickness was measured on the right hand side of the body in duplicate at 4 sites (biceps, triceps, subscapula, and suprailium) by using Harpenden skinfold calipers (British Indicators Ltd, Hertfordshire, United Kingdom). Midupper arm circumference (MUAC) was measured by using a non-stretchable steel measuring tape (Lufkin W 606 PM; Cooper Industries, Lexington, SC). The subscapular-to-triceps skinfold-thickness ratio was used as a proxy measure of peripheral compared with central fat distribution (23). Upper arm fat area (UAFA) and upper arm muscle area (UAMA) were calculated by using the equations of Frisancho (24), which are based on measurements of MUAC and triceps skinfold thickness, as follows:

\[
UAMA = \frac{MUAC - (\text{triceps skinfold thickness})}{\pi} \times \frac{1}{4 \times \pi} \quad (1)
\]

\[
UAFA = \frac{[\text{MUAC}]^2}{(4 \times \pi)} - UAMA \quad (2)
\]
TABLE 1
Anthropometric characteristics of anorexia nervosa patients and control subjects

<table>
<thead>
<tr>
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<th>Anorexia nervosa patients (n = 23)</th>
<th>Control subjects (n = 25)</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>15.46 ± 1.34 (13.40–17.80)</td>
<td>15.10 ± 1.62 (13.10–17.95)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>40.2 ± 4.6 (31.5–48.1)</td>
<td>57.3 ± 8.2 (43.5–79.9)</td>
</tr>
<tr>
<td>Weight z score</td>
<td>−1.71 ± 0.58 (−2.51 to −0.55)</td>
<td>0.36 ± 0.70 (−1.00 to 2.00)</td>
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<tr>
<td>Height (cm)</td>
<td>161.9 ± 6.2 (151.4–173.1)</td>
<td>164.3 ± 4.2 (153.4–171.0)</td>
</tr>
<tr>
<td>Height z score</td>
<td>−0.01 ± 0.95 (−1.90 to 1.73)</td>
<td>0.48 ± 0.65 (−1.14 to 1.50)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>15.3 ± 1.2 (12.3–17.7)</td>
<td>21.2 ± 2.9 (17.1–28.3)</td>
</tr>
<tr>
<td>BMI z score</td>
<td>−2.23 ± 0.46 (−3.42 to −1.02)</td>
<td>0.006 ± 0.68 (−1.28 to 1.28)</td>
</tr>
<tr>
<td>Biceps skinfold thickness (mm)</td>
<td>4.3 ± 1.3 (2.5–7.5)</td>
<td>8.6 ± 4.0 (3.5–21.2)</td>
</tr>
<tr>
<td>Triceps skinfold thickness (mm)</td>
<td>7.4 ± 2.3 (2.7–12.1)</td>
<td>14.6 ± 5.5 (8.2–28.8)</td>
</tr>
<tr>
<td>Subscapular skinfold thickness (mm)</td>
<td>5.3 ± 1.1 (3.0–8.2)</td>
<td>12.7 ± 5.8 (6.8–26.0)</td>
</tr>
<tr>
<td>Suprailiac skinfold thickness (mm)</td>
<td>5.1 ± 1.8 (3.2–10.1)</td>
<td>13.5 ± 5.2 (4.2–25.0)</td>
</tr>
<tr>
<td>Midupper arm circumference (cm)</td>
<td>19.2 ± 1.8 (14.5–22.5)</td>
<td>26.3 ± 2.7 (22.0–33.0)</td>
</tr>
<tr>
<td>Subscapular-to-triceps skinfold-thickness ratio</td>
<td>0.76 ± 0.16 (0.53–1.12)</td>
<td>0.89 ± 0.28 (0.39–1.58)</td>
</tr>
<tr>
<td>Upper arm muscle area (cm²)</td>
<td>22.7 ± 3.7 (14.8–30.7)</td>
<td>37.6 ± 6.6 (23.4–52.4)</td>
</tr>
<tr>
<td>Upper arm fat area (cm²)</td>
<td>6.7 ± 2.3 (1.9–11.2)</td>
<td>17.8 ± 7.8 (9.1–41.0)</td>
</tr>
</tbody>
</table>

1 ± SD; range in parentheses.
2 Significantly different from control subjects, P < 0.01.

Statistical analysis

SPSS software (version 8.0; SPSS, Chicago) was used for statistical analyses. A one-way analysis of variance test was used to investigate differences in body composition between anorexia nervosa patients and control subjects. Student’s t test was used to compare 1) height, weight, and BMI z scores with the National Center for Health Statistics reference population median, and 2) TBN as a percentage of that predicted for age, height, and weight with 100%. Simple Pearson correlations were used to investigate relations between simple anthropometry and reference measures of body composition (ie, DXA and TBN), TBN measurements were expressed both as raw values and as a percentage of that predicted for age, height, or weight, based on prediction equations developed from 63 healthy females. Stepwise multiple regression analysis was used to develop models that predicted percentage body fat from DXA in both anorexia nervosa patients and control subjects. All values are expressed as means ± SDs. The significance level was set at P < 0.05.

RESULTS

Subject characteristics

The anthropometric characteristics of the 23 anorexia nervosa patients and 25 control subjects of similar age are shown in Table 1. The anorexia nervosa patients were aged between 13.40 and 17.80 y, with a mean age of 15.46 ± 1.34 y. On admission, patients had a mean body weight of 40.2 ± 4.6 kg and a low BMI of 15.3 ± 2.9. As expected in this malnourished group, BMI and weight z scores were significantly lower (P < 0.01) than the reference population median of zero. The mean length of illness before admission was 10 ± 9 mo (range: 2–39 mo). All 23 patients were of the restrictive subtype; 3 also displayed purging behavior and 14 were overexercisers.

The mean age of the control group was 15.10 ± 1.62 y; the control group’s weight was 57.3 ± 8.2 kg and their mean BMI was 21.2 ± 2.9. There were no significant differences between the anorexia nervosa patients and the control group for age and height. However, there were significant differences between the 2 groups for all other anthropometric measures, with the exception of the subscapular-to-triceps skinfold-thickness ratio (Table 1).

Body composition

The results of body-composition analysis from DXA are shown in Table 2. Significant differences were found between the 2 groups for percentage of body fat, fat-free mass, trunk fat, leg fat, and trunk-to-leg fat ratio.

The TBN data for the anorexia nervosa patients is shown in Table 3. The mean TBN value in the anorexia nervosa patients was 1.1 ± 0.1 kg. TBN values, when expressed as a percentage of that predicted for age, height, and weight were low (73%, 75%, and 91%, respectively) and were significantly different from 100% by t test.

TABLE 2
Dual-energy X-ray absorptiometry characteristics of anorexia nervosa patients and control subjects

<table>
<thead>
<tr>
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<th>Anorexia nervosa patients (n = 23)</th>
<th>Control subjects (n = 25)</th>
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<tbody>
<tr>
<td>Percentage of body fat (%)</td>
<td>13.8 ± 5.8 (4.2–25.6)</td>
<td>26.3 ± 7.0 (15.6–41.5)</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>34.5 ± 4.3 (29.1–42.6)</td>
<td>41.2 ± 3.6 (35.2–48.1)</td>
</tr>
<tr>
<td>Trunk fat (kg)</td>
<td>2.1 ± 1.0 (0.5–4.7)</td>
<td>6.6 ± 2.9 (2.2–13.8)</td>
</tr>
<tr>
<td>Leg fat (kg)</td>
<td>2.6 ± 1.1 (0.5–5.0)</td>
<td>7.1 ± 2.8 (3.7–15.4)</td>
</tr>
<tr>
<td>Trunk-to-leg fat ratio</td>
<td>0.79 ± 0.18 (0.56–1.24)</td>
<td>0.93 ± 0.20 (0.44–1.36)</td>
</tr>
</tbody>
</table>

1 ± SD; range in parentheses.
2 Significantly different from control subjects: 2P < 0.01, 2P < 0.05.
Correlations between simple anthropometry and reference measures

Simple correlations between DXA-derived measurements of body composition and anthropometry are shown in Table 4. In anorexia nervosa patients, the most significant correlation was found between triceps skinfold thickness and percentage of body fat ($r = 0.83$, $P < 0.0001$), which was also highly correlated in the control group ($r = 0.79$, $P < 0.0001$). These correlations are shown graphically in Figure 1. BMI was also correlated with percentage of body fat (DXA), although this correlation was far stronger in the control subjects ($r = 0.85$, $P < 0.0001$) than in the anorexia nervosa patients ($r = 0.46$, $P < 0.05$). MUAC and UAFA were also correlated with percentage of body fat in both groups. Subscapular-to-triceps skinfold-thickness ratio correlated with percentage of body fat in the anorexia nervosa patients but not in the control subjects. BMI z score, weight, and weight z score correlated with percentage of body fat in the control subjects, but not in the anorexia nervosa patients.

None of the anthropometric measures in the anorexia nervosa patients correlated with trunk to leg fat ratio. In the control group, however, subscapular skinfold thickness, suprailliac skinfold thickness, and the subscapular-to-triceps skinfold-thickness ratio each correlated significantly with trunk-to-leg fat ratio.

The simple correlations between anthropometric measures and TBN-derived data for the anorexia nervosa patients are shown in Table 5. TBN and TBN as a percentage of that predicted for age correlated most significantly with weight and weight z scores, respectively. The relation between TBN and body weight is shown in Figure 2. TBN was also correlated with BMI, BMI z score, and UAMA. However, the very low BMI and TBN values of one subject and the relatively high TBN value of another subject appeared to influence these correlations. When these 2 subjects were excluded from the analysis, no significant correlation was found between TBN and BMI, BMI z score, and UAMA. Note that both of these subjects were overexercisers and one was severely malnourished on admission to the hospital. When these 2 subjects were excluded from the analysis, the correlations between TBN and weight ($r = 0.79$, $P < 0.0001$) and TBN and weight z score ($r = 0.57$, $P = 0.007$) were still significant.

Regression analysis

Stepwise multiple regression analysis was used to develop models to predict percentage of body fat (DXA) in anorexia nervosa patients and control subjects (Table 6). We included the following possible predictor variables: age, weight, weight z score, BMI, BMI z score, MUAC, and biceps, triceps, subscapular, and suprailliac skinfold thicknesses. We checked for interaction effects, such as that between age and weight and age and BMI, but none were significant. In anorexia nervosa patients, triceps skinfold thickness was the most significant predictor of percentage of body fat and explained 68% of the variance. However, in control subjects, MUAC, triceps skinfold thickness, and suprailliac skinfold thickness were each significant predictors of percentage of body fat and together explained 88% of the variance.

DISCUSSION

In the present study we found that adolescents who were hospitalized with anorexia nervosa were significantly wasted, with depletion of both total body fat and total body protein, but had no evidence of stunting. This suggests that the malnutrition was not of sufficient duration to have a significant effect on linear growth. In addition, significant correlations were found between simple anthropometric measurements and the more sophisticated body composition techniques of DXA and TBN determination. In particular, there were significant correlations between 1) triceps...
skinfold thickness and percentage of body fat (DXA), 2) body weight and TBN, and 3) BMI and percentage of body fat (DXA).

The anorexia nervosa patients in our study had a mean TBN value of 1.1 ± 0.1 kg. These values for TBN, when expressed as a percentage of that predicted for age, height, and weight were low (73 ± 10%, 75 ± 7%, and 91 ± 7%, respectively). Although the level of protein depletion found in the current study agrees with the findings of Russell et al (7) and Kooh et al (13) in older females with anorexia nervosa, it is also consistent with other studies of patients who have significant amounts of wasting (25, 26). For example, in a study of 21 malnourished children and adolescents with cystic fibrosis who had mean weight z scores similar to those of our patients, there were comparable degrees of protein depletion (mean value of TBN as a percentage of that predicted for age was 70% and for height was 86%). However, less severe depletion of protein was seen in children and adolescents with chronic liver disease (mean TBN as a percentage of that predicted for age and height was 83% and 88%, respectively, n = 10) and juvenile chronic arthritis (mean TBN as a percentage of that predicted for age and height was 83% and 90%, respectively, n = 31) (25).

One of the major findings of the current study was the significant level of body fat depletion in anorexia nervosa patients (12.5% lower than control subjects). To investigate whether fat distribution is affected by weight loss in anorexia nervosa patients, we used DXA-derived trunk and leg fat values and anthropometric measures of subscapular and triceps skinfold thickness. These have been used as proxy measures of abdominal and peripheral fat (5, 15, 23). In our study, anorexia nervosa subjects were found to have a 15% lower DXA-derived trunk-to-leg fat ratio than did control subjects. This suggests that anorexia nervosa subjects have lower abdominal fat distribution. However, there was no significant difference in fat distribution between the anorexia nervosa patients and control subjects with the use of the anthropometrically determined subscapular-to-triceps skinfold-thickness ratio. Waist circumference and waist-to-hip ratio are additional anthropometric measures that have been used to estimate abdominal fat distribution (27). However, in this study, waist and hip circumference were not measured in control subjects and therefore we were unable to investigate how these measures related to DXA-derived data on fat distribution. Future studies to investigate central compared with peripheral fat distribution in anorexia nervosa patients should also include measurements of both the waist circumference and the waist-to-hip ratio.

To assess whether simple clinical measurements of skinfold thickness are of value when determining the level of body fat depletion, we investigated the relations between these measures and percentage of body fat (DXA). In both the anorexia nervosa patients and control subjects, triceps and subscapular skinfold thickness, MUAC, and UAFA (calculated by using triceps skinfold thickness) were significantly correlated with percentage of body fat (DXA). In control subjects, but not in anorexia nervosa patients, there were also strong associations between percentage of body fat (DXA) and several other anthropometric measures (BMI z score, weight, and weight z score). A previous study in healthy preadolescent children found similar significant correlations between body fat content from DXA and anthropometric measures (triceps skinfold thickness, subscapular skinfold thickness, and body weight) (28). In addition, in the current study, the association between BMI and percentage of body fat (DXA) was stronger in control subjects than in anorexia nervosa patients. These results show that traditional measures of body fatness, such as weight, weight z score, BMI, and BMI z score, do not

<table>
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<th>TABLE 5</th>
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<tr>
<td>Correlations between anthropometric measures and total body nitrogen (TBN)–derived data for anorexia nervosa patients</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Weight</td>
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<td>Weight z score</td>
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<tr>
<td>BMI</td>
</tr>
<tr>
<td>BMI z score</td>
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<tr>
<td>Upper arm muscle area</td>
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</tbody>
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$^1$P < 0.0001.
$^2$P < 0.01.
$^3$P < 0.05.
give as accurate an indication of body fatness in adolescent anorexia nervosa patients as they do in healthy adolescent females. Instead, the simple measure of triceps skinfold thickness appears to be a better indicator of percentage of body fat (DXA) in adolescent anorexia nervosa patients.

The latter finding for percentage of body fat (DXA) was further investigated by using stepwise multiple regression analysis. This analysis confirmed that the triceps skinfold thickness was the most significant predictor of percentage of body fat (DXA) and explained 68% of the variance. In contrast, in control subjects, MUAC, triceps skinfold thickness, and suprailiac skinfold thickness were each independent predictors of percentage of body fat (DXA) and together explained 88% of the variance.

In anorexia nervosa patients, TBN was significantly correlated with body weight, weight z-score, BMI, BMI z-score, and UAMA, with body weight and weight z-score being the most significant. In addition, TBN as a percentage of that predicted for age was significantly correlated with weight and weight z-score (body weight adjusted for age). These findings may have useful clinical implications because many units do not have the availability of sophisticated body-composition tools to aid nutritional assessment. Therefore, the simple anthropometric measures of weight and weight z-score may prove useful as indicators of body protein and body protein adjusted for age, respectively.

TABLE 6
Multiple regression analysis of factors predicting percentage of body fat (dual-energy X-ray absorptiometry) in anorexia nervosa patients and control subjects

<table>
<thead>
<tr>
<th>Predictors</th>
<th>β</th>
<th>P</th>
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<tr>
<td>Anorexia nervosa patients (R^2 = 0.68)</td>
<td></td>
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</tr>
<tr>
<td>Triceps skinfold thickness</td>
<td>2.14 ± 0.32</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Constant</td>
<td>−1.91 ± 2.46</td>
<td>0.446</td>
</tr>
<tr>
<td>Control subjects (R^2 = 0.88)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midupper arm circumference</td>
<td>1.13 ± 0.31</td>
<td>0.001</td>
</tr>
<tr>
<td>Triceps skinfold thickness</td>
<td>0.50 ± 0.13</td>
<td>0.001</td>
</tr>
<tr>
<td>Suprailiac skinfold thickness</td>
<td>0.39 ± 0.12</td>
<td>0.003</td>
</tr>
<tr>
<td>Constant</td>
<td>−15.99 ± 6.18</td>
<td>0.017</td>
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\(±\)SE.

The current study confirms that adolescents with anorexia nervosa are significantly depleted in both body fat and protein, comparable to other chronic diseases associated with wasting. We also identified important clinical tools that are simple, inexpensive, and relatively noninvasive with which to assess body composition in malnourished adolescents with anorexia nervosa. These tools include triceps skinfold thickness, which was the most significant predictor of percentage body fat, explaining 68% of the variation, and body weight, which was shown to be a good indicator of TBN and therefore of the level of protein depletion.

It is noteworthy that percentage of body fat (DXA) was significantly correlated with BMI, although not as highly as the triceps skinfold thickness in anorexia nervosa patients. Therefore, in the absence of a trained anthropometrist with properly calibrated skinfold calipers to measure triceps skinfold thickness, a clinician may choose to measure BMI as an indicator of body fatness.

The major findings of this study have a practical application and will prove to be useful in clinical practice. The use of the simple measure of body weight as an indicator of body protein and triceps skinfold thickness as an indicator of percentage of body fat obviates the need for more sophisticated, expensive, and hazardous techniques. These simple clinical tools can therefore be used to evaluate nutritional status in female adolescents with anorexia nervosa.

We are grateful to the anorexia nervosa patients who committed their time to this study. We also thank Madeleine Thompson for her assistance with running the DXA machine and for her work in reanalyzing DXA scans from patients tested in 1999 with Y2K compliant adult software. We gratefully acknowledge the support of Robert Howman-Giles in allocating time for us to use the hospital’s DXA machine for this research.

REFERENCES