Expected Body Weight in Adolescents: Comparison Between Weight-for-Stature and BMI Methods

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KEY WORDS: adolescence, body weight, eating disorders, BMI

ABBREVIATIONS
CDC—Centers for Disease Control and Prevention
EBW—expected body weight
GAM—generalized additive model
NCHS—National Center for Health Statistics
NHES—National Health Education Survey
WFS—weight-for-stature

abstract

OBJECTIVE: To test the hypothesis that the weight-for-stature (WFS) and BMI methods are not equivalent in determining expected body weight (EBW) in adolescents with eating disorders and to determine the sensitivity, specificity, and positive predictive value of each method to detect those <75% EBW. We hypothesized that differences in EBW would be greatest at the extremes of height.

METHODS: EBW was determined for 12,047 individual adolescents aged 12 to 19 years by the WFS and BMI methods by utilizing the same National Center for Health Statistics data sets. Absolute difference between the 2 methods for each individual was calculated and plotted against height by using a generalized additive model. The number of individuals whose weights were <75% EBW was determined by each method.

RESULTS: For girls, EBW was 3.52 ± 3.13% higher when using the WFS method compared with the BMI method. For boys, EBWWFS was 3.45 ± 2.72% higher than EBWBMI. Among adolescent girls, 65% had EBWWFS higher than EBWBMI. By using the EBWWFS method as the gold standard, specificity of the EBWBMI method to detect those <75% EBW was 0.999, but sensitivity was only 0.329. Absolute differences in EBW were most pronounced at the extremes of height.

CONCLUSIONS: The WFS and BMI methods are not equivalent in determining EBW in adolescents and are not interchangeable. EBWWFS was ∼3.5% higher than EBWBMI. In adolescents with eating disorders, use of the BMI method will underestimate the degree of malnutrition compared with the WFS method. Which method better predicts meaningful clinical outcomes remains to be determined. Pediatrics 2012;130: e1607–e1613

WHAT’S KNOWN ON THIS SUBJECT: In adolescents with eating disorders, percent expected body weight (EBW) is used for diagnosis and to make clinical decisions. The assumption is that the weight-for-stature (WFS) and BMI methods of determining EBW are equivalent, but that may not be true.

WHAT THIS STUDY ADDS: This study demonstrates that EBWWFS is ∼3.5% higher than EBWBMI. Differences are most pronounced at extremes of height. Compared with the EBWWFS method, sensitivity of EBWBMI to detect those <75% EBW is low.

ARTICLE

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Both overweight and underweight in childhood and adolescence are associated with increased morbidity and mortality in adulthood.\(^1\)\(^-\)\(^4\) Although the prevalence of overweight and obesity among adolescents in the United States and globally has increased dramatically over the past 3 decades,\(^5\)\(^-\)\(^7\) pediatric undernutrition also remains a major problem worldwide. In developing countries, the degree of malnutrition in childhood is a predictor of increased mortality.\(^8\) In the United States, eating disorders constitute a major cause of underweight in adolescents. Despite advances in treatment, mortality remains at 2% to 10%. The degree of malnutrition, usually referred to as the percentage of expected body weight (EBW), is used clinically for current diagnostic criteria for anorexia nervosa\(^9\) and for recommendations as to when to admit a patient to an inpatient facility for severe malnutrition. Guidelines from a number of professional organizations recommend hospitalizing a patient who is <75% EBW\(^9\)\(^-\)\(^11\).

A BMI (weight in kilograms divided by the square of height in meters) greater than the 95th percentile for age and gender during adolescence is associated with increased morbidity and mortality during adulthood;\(^12\)\(^-\)\(^15\) but BMI cutoffs at the lower end of the weight spectrum in adolescence, for those who are underweight, have not been agreed on.\(^14\) There are challenges in determining EBW in adolescents because of rapid changes in height, weight, and body composition during puberty and individual variations in the timing of the pubertal growth spurt. Different methods of determining EBW based on measurements of both height and weight use different reference data for adolescents. The weight-for-stature (WFS) method uses tables of weight for height and age with data sets from National Center for Health Statistics (NCHS) tables using data from the National Health Education Survey (NHES) Cycle III (1966–1970).\(^15\) The BMI method is used to calculate EBW from median BMI for age determined from the 2000 Centers for Disease Control and Prevention (CDC) growth references (available at www.cdc.gov/growthcharts).\(^16\) The 2000 CDC growth references for 6- to 19-year-olds use data from NHES III, but add data from the NHANES I (1971–1974), and NHANES II (1976–1980). The 2000 CDC growth references, however, do not include WFS references for adolescents.

The assumption of many clinicians caring for adolescents is that the WFS and the BMI methods produce equivalent EBW determinations, but they may not do so. Such an assumption, if incorrect, has important implications both clinically and for research. We generated updated reference data of WFS for age for healthy US adolescents. Our primary aim was to determine whether WFS and the BMI methods are equivalent, particularly in detecting those <75% EBW. We approached this question by computing sensitivity, specificity, and positive predictive value for each method. Our secondary aim was to evaluate the effect of height on the difference in EBW between the 2 methods. We hypothesized that the absolute difference in EBW would be most pronounced at the extremes of height.

**METHODS**

EBW was determined for 12,047 individual adolescents aged 12 to 19 years by using the WFS and BMI methods utilizing the same NCHS data sets, including NHES Cycle III, NHANES I, and NHANES II. We did not use data from NHANES III, because in the development of the 2000 CDC growth charts, weight data for children older than 6 years were deliberately excluded because of the increasing prevalence of obesity between NHANES II and NHANES III.\(^17\) The NHES III was conducted on a nationwide probability sample of 7514 youth aged 12 to 17 years. Of the 7514 youth, 6768 (90%) were examined. Adjusted sampling weights were computed so as to closely reflect the 23 million youth in the US population at that time in terms of age, sex, and certain other demographic characteristics. The NHANES I was conducted on a nationwide probability sample of ~32 000 persons 1 to 74 years of age. The NHANES I sample was selected so that certain population groups thought to be at high risk of malnutrition (persons with low incomes, preschool-aged children, women of childbearing age, and the elderly) were oversampled at preset rates. Of the 23 808 subjects examined, 2666 were adolescents (age at examination: 12–19 years old). The NHANES II is a nationwide probability sample of 27 801 persons from 6 months to 74 years of age with children and persons classified as living at or below the poverty level sampled at rates substantially higher than their proportions in the general population. From this sample, 25 286 people were interviewed, 20 322 were examined, and 2613 of those examined were adolescents. Of the 12 047 adolescents examined, there were no missing data for the variables (ie, age at examination, sex, weight, and height) included in our analyses. The NHES and NHANES are data sets made available by the NCHS of the CDC.

Using data from the 12,047 individual adolescents, we generated new tables for EBW, WFS (EBWWFS) and EBWBMI (see Supplemental Tables). We computed new sample weights for the combined data sets as described by the NHANES analytic guidelines.\(^18\) All analyses incorporating such sampling weights also took into account differential probabilities of selection and nonresponse. EBWWFS for the category with sample size <6 was set to missing, resulting in 11 847 subjects available for further analysis.

For each individual, we computed 2 measures:
1. WFS method: EBW\textsubscript{WFS} was defined as the median weight in kilograms by sex, age (in half-year increments), and height group in centimeters. The age and height categories we used were identical to the original NCHS tables utilizing data from the NHES Cycle III (1966–1970).

2. BMI method: EBW\textsubscript{BMI} was defined as median BMI for age and sex obtained from data used to draw the 2000 CDC BMI growth charts. BMI-for-age values were available for each month of age from 24 months (2 years) through 240 months (20 years), tabulated at the midpoint of each month and truncated to the last full month. Median BMI was multiplied by height (in meters) squared to calculate EBW in kilograms. EBW derived from the BMI method for each individual was further tabulated by sex, age (in half-year increments), and height group to correspond to the WFS tables. The 50th percentile of EBW in each age and height category was designated as EBW\textsubscript{BMI}.

The arithmetic and absolute arithmetic differences and their corresponding percentage differences of EBW for each subject were calculated. These measurements are presented as mean ± SD. The Pearson correlation coefficient was used to examine the relationship of EBW derived from both WFS and BMI methods. Figures were plotted to compare EBW by the 2 methods for hypothetical subjects of certain heights by age for both boys and girls.

A generalized additive model (GAM), a nonparametric method, was used to model the association between height or age and absolute difference of the 2 EBW methods, stratified by sex.\textsuperscript{19} We computed GAM plots by using the R programming language, version 2.14.1.\textsuperscript{20} The number of individual adolescents whose weights were below or above the 75% EBW threshold was determined for each method. Sensitivity, specificity, positive predictive values, and negative predictive values were computed assuming EBW\textsubscript{WFS} and then EBW\textsubscript{BMI} as the gold standard of comparison. Other than GAM, all statistical analyses were conducted by using SAS software, version 9.2 (SAS Institute, Cary, NC).

**RESULTS**

Of the 12,047 observations, WFS was available for 11,847 subjects between the ages of 12 and 19 years, 6114 male subjects and 5733 female subjects. Data by age, sex, and height group in kilograms and centimeters and in pounds and inches are shown in the Supplemental Tables. For girls, the mean ± SD absolute difference in kilograms between EBW\textsubscript{WFS} and EBW\textsubscript{BMI} was 1.80 ± 1.60 kg (range: 0.00–14.46), with a mean percentage difference of 3.52% ± 3.13% (range: 0.00–33.16). Among the female subjects, 65.11% (3733) had EBW\textsubscript{WFS} higher than EBW\textsubscript{BMI}. For boys, the mean ± SD absolute difference in kilograms between EBW\textsubscript{WFS} and EBW\textsubscript{BMI} was 1.91 ± 1.54 kg (range: 0.00–15.62), with a mean percentage difference of 3.45% ± 2.72% (range: 0.01–20.36). Among the male subjects, 55.02% (3364) had EBW\textsubscript{WFS} higher than EBW\textsubscript{BMI}. The correlation coefficient between the 2 methods was 0.97 for boys and 0.98 for girls.

Figures 1 and 2 illustrate differences in EBW for girls aged 12 to 19 years with a height of 160 cm (63 in) and for boys aged 12 to 19 years with a height of 165 cm (65 in) determined by using the 2 methods. These heights were chosen as illustrations because they best represent the mean height of girls and boys aged 12 to 19 years in these nationally sampled data.

Figure 3 demonstrates the relationship between height and predicted absolute difference of the 2 EBW methods for boys and girls separately. A strong nonlinear association was observed for these relationships. Differences in EBW between the 2 methods were most pronounced at the lower and upper ends of the height ranges included in this adolescent sample and were more pronounced among girls. The minimum differences of the 2 EBW methods were observed among girls who were 1.57 m in height and among boys who were 1.60 m in height. Figures 4 and 5 show relationships for combined effects of age and height on predicted difference of the 2 EBW methods. For both female and male subjects the influence of height controlled for age showed a stronger relationship than did age.
controlled for height. Again, these relationships were more pronounced among female subjects.

Using the EBW_{WFS} method, we determined that of the 11,847 subjects, 73 (0.62%) had a body weight <75% EBW. Using the EBW_{BMI} method, we determined that 41 subjects (0.35%) were <75% EBW. Sensitivity, specificity, positive predictive value, and negative predictive values determined by using each method as the gold standard are shown in Table 1. By using the EBW_{WFS} method as the gold standard, specificity of the EBW_{BMI} method to detect those <75% EBW was 0.999 (95% confidence interval: 0.998–0.999) but sensitivity was only 0.329 (95% confidence interval: 0.225–0.449).

**DISCUSSION**

Using a large nationally representative sample of adolescents, this study demonstrates that EBW_{WFS} and EBW_{BMI} are not equivalent measures but are highly correlated. In general, but especially for girls, EBW_{WFS} was ∼3.5% higher than EBW_{BMI}. Compared with the WFS method, use of the BMI method to estimate EBW will underestimate the degree of malnutrition. The opposite is the case when considering the EBW_{BMI} method as the standard. Compared with the EBW_{WFS} method, the sensitivity of the EBW_{BMI} method to detect an adolescent <75% EBW was low, but specificity was excellent. From a practical point of view, use of EBW_{BMI} as a reference will result in fewer patients with eating disorders meeting current criteria for anorexia nervosa, fewer patients meeting the 75% EBW threshold criterion for hospitalization, and most importantly, patients being given a lower treatment goal weight range. Use of 1 method instead of the other may have important clinical and economic implications.

In almost two-thirds of girls, EBW_{WFS} was 1.8 ± 1.6 kg, the difference for an individual patient varied as much as 14.5 kg, particularly at the extremes of height in the sample. Pediatricians are familiar with the concept of a healthy weight range for a particular age and height, but until now, tables of WFS for age for adolescents utilizing the updated data sets
were not available. Clinicians now have the option to use these WFS tables provided in the Supplemental Tables as a reference to determine EBW for their patients to help make treatment decisions. These updated tables have the advantage that, in contrast to the original NCHS WFS tables, the updated tables use the same data sets from which the 2000 CDC growth charts were drawn.

Le Grange et al recently illustrated the difficulties in comparing the BMI method of determining EBW with 2 other methods sometimes used in the pediatric population, the McLaren and Read methods, and Moore et al methods. Direct comparisons could be made only in 204 of 373 adolescent subjects (55%). The McLaren method could not be used to calculate EBW for girls taller than 163 cm (64 in) or for boys taller than 176 cm (69.3 in). Both the McLaren and Moore methods make assumptions not supported by data, particularly in the adolescent age group. The McLaren method, which does not take into account age, assumes that the weight-for-height ratio is a constant. Although this assumption is generally true for younger children before puberty, it is not true in adolescence. In fact, the original 1977 charts of WFS specified that they were to be used only for prepubertal girls and boys. The Moore method assumes that a patient on a certain percentile for height should be on the same percentile for weight, which is not correct. The CDC height-for-age and weight-for-age charts are 2 separate and independent plots. As we have previously described, it is an error to assume that a 16-year-old who is on the 90th percentile for height for age (ie, who is tall) should be on the 90th percentile for weight for age (ie, overweight).

Indeed, the only 2 methods that determine weight for both age and height are the WFS and BMI methods, the 2 methods we compared. We examined the differences in EBW in 11,847 individual adolescents between the ages of 12 and 19 years by using the same data sets and found that the 2 methods of determining EBW are not equivalent. Put another way, median weight for age and height does not reveal the same information as median BMI for age.

Each of the methods of determining EBW has limitations. Both methods are based on cross-sectional data. Percentiles on the height, weight, and BMI charts do not necessarily reflect longitudinal trajectories of individual patients, particularly during adolescence because of variations in the rate and tempo of puberty. Both early- and late-maturing adolescents will cross percentiles of height, weight, and BMI. Neither method takes into account growth retardation, which occurs in states of malnutrition, including anorexia nervosa. The WFS method groups individuals of the same age and gender by height ranges (eg, 160.0–164.9 cm) and does not differentiate between EBW for an individual with a height of 160.0 cm and one with a height of 163.0 cm, for example. The BMI charts reflect smoothed curves of BMI for age, but despite the large number of youths studied, the number measured at each height is still relatively small. Finally, there is danger of oversimplification. Both methods provide reference data to help describe an individual patient’s state of nutrition with reference to a standard sample. They do not define optimal weight for health for that individual patient.
Patients at or near 100% EBW can still be medically compromised in the presence of severe weight loss or unhealthy weight control behaviors. Recognizing this fact, in the proposed changes for the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, the threshold weight criterion for anorexia nervosa will most likely be eliminated. In addition to height and weight, individualized healthy goal weight ranges should take into account previous height and weight percentiles, pubertal stage, growth potential, and objective outcomes reflecting return to health, such as resumption of menses.

The optimal method of determining EBW will be that method that best predicts clinical outcomes. For example, do patients with anorexia nervosa who are <75% EBW by 1 method but not by the other, and therefore do not get hospitalized, do any worse than those who are hospitalized? Our study was not designed to answer that question, but such studies need to be conducted to inform clinical and policy decisions. In adolescent girls with anorexia nervosa, using WFS to determine EBW, we have previously shown that achievement of a weight $91.6 \pm 9.1\%$ EBW was associated with resumption of menses within 3 to 6 months. Based on the current study, using the BMI method, resumption of menses is likely to occur at a weight $\sim 95\%$ EBW.

It is not clear why the differences in EBW using the 2 methods are greatest at the extremes of height. A likely reason is that the number of observations becomes smaller the further from the median, and therefore more variability at the extremes of height contributes to the differences. It is also possible that there is a mathematical reason. The WFS method calculates median weight within a particular height category and then compares an individual parameter (weight) to the median weight. The BMI method calculates median BMI of the entire sample population and then multiplies median BMI by the individual’s height squared. BMI is a measure of adiposity and by convention, the exponent of 2 is used for height for all ages because it correlates well with body fat and future morbidity. An exponent for height of 2 during adolescence may be imperfect, however, as demonstrated by Cole, who suggested that an exponent of 3 for height may better describe the relationship between body mass, weight, and height during puberty. It is possible that multiplying median BMI by height to the power of 2 instead of a higher exponent, such as 3, may result in a lower EBW with the BMI method and that the differences will be more pronounced at the extremes of height.

We generated updated reference tables of WFS and age for healthy US adolescents and found that the WFS and the BMI methods of determining EBW are not equivalent and therefore not interchangeable. Overall, EBW$_W$ was

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<th>Gold Standard and Parameter</th>
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<td>EBW$_W$ Sensitivity</td>
<td>0.329</td>
<td>0.223–0.449</td>
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<tr>
<td>Specificity</td>
<td>0.999</td>
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<td>PPV</td>
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<tr>
<td>EBW$_B$ Sensitivity</td>
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<td>NPV</td>
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~3.5% or 1.8 kg higher than EBW_{BMI} especially for girls. The differences in EBW by the 2 methods were most pronounced at the extremes of height. Use of the BMI method will underestimate the degree of malnutrition compared with the WFS method. Compared with the EBW_{WFS} method, sensitivity of EBW_{BMI} to detect those <75% EBW was low. Which method better predicts meaningful clinical outcomes remains to be determined. Most importantly, once the answer to this question has been determined, clinicians and researchers should then use a common reference and a common language.

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**REFERENCES**

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