A New BIA Equation Estimating the Body Composition of Young Children

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Bioelectric impedance analyses (BIA) provides a valid and reliable measure of body composition in field, clinical, and research settings if standard protocol procedures are followed, and population-specific equations are available and utilized. The objective of this study was to create and cross-validate a new BIA body composition equation with representative healthy weight (HW), overweight (OW), and obese (OB) young children. Participants were 436 children who were 5–11 years of age. Dual-energy absorptiometry fat-free mass (FFM) was used as the criterion measure and a single frequency tetra-polar BIA device was used to create the new BIA equation. The new BIA equation explained 95.2% of the variance in FFM with no statistical shrinkage upon cross-validation. The use of this equation may help to identify effective intervention strategies to prevent or combat childhood obesity, and may assist in additional conditions or treatments where information concerning body composition measures would provide greater accuracy and sensitivity measures for preventing or combating disease.

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INTRODUCTION

Childhood obesity (BMI for age and sex >95th percentile) has dramatically increased among children aged 6–11 years over the past 30 years, increasing from 6.5% in 1980 to 19.6% in 2008 (1). This is cause for great concern because an estimated 77% of obese (OB) children remain OB throughout their adult life and obesity during childhood can be a significant risk factor for adult morbidity and mortality (2–6). This is due to numerous health consequences and medical complications related to obesity including heart disease, hypertension, and many metabolic derangements including type 2 diabetes, hyperlipidemia and hypercholesterolemia, sleep apnea, orthopedic issues, as well as social and psychological problems (5,7–11). There have been great efforts made to bring public awareness of this ever rising medical crisis, and effective intervention strategies to prevent or combat obesity among children are earnestly being sought. One of the difficulties of conducting research in both OB and nonobese children is identifying a safe, noninvasive, economical (cost and time), and valid method of assessing body composition that can be used in the laboratory, as well as a clinic or field setting. Bioelectric impedance analysis (BIA) fulfills many of the requirements to be considered for an optimal body composition method. Previously, many BIA body composition prediction equations have been developed for a variety of child and adolescent populations (12–25). However, many of the BIA equations for children were developed when a greater percentage of the children were categorized as having healthy weight (HW; BMI for age and sex between the 5th and the 84th percentile), prior to the exponential rise in the number of overweight (OW; BMI for age and sex between the 84th and the 94th percentile) and OB (BMI for age and sex >95th percentile) children. Without the proper representation of these samples of children, the validity in the development of previous equations may be compromised as it cannot be assumed that the equations can be readily applied to populations that vary considerably from the original reference population. This lack of representation of OW and OB children in addition to the over-representation of healthy weight children (BMI for age and sex <85th percentile) in the development or BIA equations may then lead to inaccurately estimating the body composition of a significant portion of the current pediatric population, may lead to misidentification of children most in need of obesity preventing and combating intervention strategies, and may lead to erroneous conclusions concerning the effectiveness of intervention strategies. Therefore, the purpose of this study was to develop and cross-validate a pediatric specific BIA equation using a more BMI diversely representative group of young children.

METHODS AND PROCEDURES

Subjects

The subjects for this study included a total of 436 white, non-Hispanic children aged 5–11 years. The children used in the BIA equation

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development portion of this study included 203 boys (137 healthy weight (HW), 32 OW, and 34 OB) and 158 girls (110 HW, 29 OW, and 19 OB). The children used for cross-validation of the newly developed equation included 38 boys (29 HW, 4 OW, and 5 OB) and 37 girls (25 HW, 9 OW, and 3 OB). Prior to participation parental consent and verbal assent were obtained for each subject in accordance with the policies and procedures of the University of Kentucky Office of Research Integrity.

Anthropometric and body composition measures

All subjects completed anthropometric and body composition measures including standing height, body mass, BIA measures, and a total body dual-energy X-ray absorptiometry (DXA) scan during a single testing session. All subjects were measured in light-weight clothing containing no metal and without shoes.

Standing height and body mass measures

Standing height was determined using a wall-fixed stadiometer (Seca Model 216; Seca North American West, Ontario, CA) with the subjects' hands positioned on the hips during a maximal inhalation. Body mass was determined using a calibrated electronic scale (Tanita Corporation Model BWB-627A; Tanita, Arlington Heights, IL).

BIA

Each subject underwent a BIA performed using a tetra-polar device (Bodystat 1500; Bodystat, Isle of Man, British Isles). All children were measured in an assumed normally hydrated state and had not eaten or participated in physical activity a minimum of 90 mins prior to being measured. The subjects were instructed to lie supine on a nonconductive padded mat and sensor surface electrodes were placed on the right wrist (bisecting the head of the ulna) and the right ankle (bisecting the medial and lateral malleoli), and source surface electrodes were placed on the right hand and foot at the base of the metacarpal-phalangeal joint. A single frequency (50 khz) was introduced through the source electrodes and the resulting current impedance measure was recorded for future analyses. The BIA procedure was performed twice consecutively, and the mean of the resulting impedance measures was used for subsequent analyses.

DXA scans

To provide the criterion measure of body composition, fat-free mass (FFM defined as the addition of the DXA mineral-free lean mass and bone mineral content; kg) was determined using total body DXA scans. All DXA scans were performed by a single trained investigator using a Lunar DPX-IQ (GE/Lunar, Madison, WI) with the scan mode selection based on sagittal diameter. Prior to scanning, subjects were instructed to remove all metal such as eye glasses and jewelry, and scans were subsequently analyzed using software version 4.7.

Statistical analyses

Following the collection of all data, 17% of the measures were stratified (based on age, sex, and BMI categorization) and randomly selected to be removed from the original data set to be used for cross-validation purposes. Physiological and theoretically relevant measures and their squared values were chosen as likely contributing factor for the BIA FFM predictive equation development. Correlation analyses were then used to identify the specific variables that would be used to develop the new BIA equation, and stepwise regression analyses were used to develop and cross-validate the newly developed BIA equation. In addition, the root mean square error and the pure error were determined for the newly developed regression equation and the cross-validation analysis, respectively. Significance was determined at $P < 0.01$ and Minitab 15 (Minitab, State College, PA) statistical software was used to perform the analyses. Modified (criterion DXA FFM only shown on the X-axis) Bland–Altman plots were used to graphically demonstrate the differences and the 95% confidence intervals between the DXA (criterion measure) FFM and the newly developed BIA equation FFM (26).

Table 1 Characteristics of the subjects used to create and cross-validate the new bioelectrical impedance analysis equation

Characteristic	Mean ± s.d.	Range
Subjects used to create equation (n = 361)		
Age (years)	8.7 ± 1.9	5.0–11.9
Body mass (kg)	33.0 ± 12.6	14.4–101.8
Standing height (cm)	133.4 ± 13.2	99.4–172.3
BMI (kg/m^2)	18.0 ± 3.9	12.8–41.1
Subjects used to cross-validate equation (n = 75)		
Age (years)	8.7 ± 1.9	5.0–11.9
Body mass (kg)	32.1 ± 11.0	13.8–76.1
Standing height (cm)	133.8 ± 12.7	102.5–156.4
BMI (kg/m^2)	17.4 ± 3.4	13.1–31.1

RESULTS

Demographic and descriptive characteristics for the subjects used in the development of the new BIA equation and used to cross-validate the new equation are presented in Table 1. Results of the preliminary correlation analyses were used to select variables for the subsequent regression analysis and thus generate the new pediatric specific BIA equation. The variables selected included standing height, body mass, and BIA impedance measures. Prior to final generation of the new BIA equation, the variables selected were examined for both skewness and Kurtosis. The somewhat lenient value of 2.0 or less was chosen as acceptable values for both skewness and Kurtosis. The resulting skewness and Kurtosis values were 0.20 and −0.41, 1.61, and 3.81; and 0.31 and 0.47 for standing height, body mass, and the BIA impedances measures, respectively. The 3.81 Kurtosis values for body mass was an indication of "heavy tails," due to high values as the cause of this inflation. Thus, the distribution of body mass was non-normal due to the inclusion of a small number of children with excessive high body mass. Despite this non-normal distribution, review of the normal probability plots of residuals (response of FFM) demonstrated only a slight nonlinearity, and thus linear modeling was employed. Table 2 shows the mean and standard error of estimate of these variables, the DXA FFM, DXA fat mass, DXA %fat, and the resulting estimates of the FFM, fat mass, and %fat from the new BIA equation for the subjects used to generate the new equation, and the subjects used to cross-validate the new equation. The new pediatric specific BIA equation was:

$$\text{DXA FFM (kg)} = (-7{,}655 + 297\,(\text{Ht}) + 125\,(\text{BM}) - 17.4\,(\text{Imp}))/1{,}000$$

where Ht, standing height (cm); BM, body mass (kg); and Imp, BIA impedance (ohms).

The new BIA equation explained a significant amount (95.2%) of the variance in DXA FFM (**Figure 1**). The root mean square error for the new BIA equation FFM was 1.4 kg.

Table 2 Measured variables used to generate and cross-validate the new BIA equation, and resulting FFM, fat mass, and %fat from new BIA equation

Variable	Mean ± s.e.	Range
Subjects used to create equation (n = 361)		
Body mass (kg)	33.0 ± 0.7	14.4–101.8
Standing height (cm)	133.4 ± 0.7	99.4–172.3
BIA impedance measure (ohms)	686.8 ± 4.0	452.0–919.0
DXA FFM (kg)	24.2 ± 0.3	12.0–55.7
DXA fat mass (kg)	7.7 ± 0.4	1.0–57.1
DXA %fat (%)	20.9 ± 0.6	5.6–57.8
BIA equation FFM (kg)	24.1 ± 0.3	10.2–44.0
BIA equation fat mass (kg)	8.9 ± 0.4	1.3–60.4
BIA equation %fat (%)	24.0 ± 0.5	6.4–59.4
Subjects used to cross-validate equation (n = 75)		
Body mass (kg)	32.1 ± 1.3	13.8–76.1
Standing height (cm)	133.8 ± 1.5	102.5–156.4
BIA impedance measure (ohms)	697.6 ± 9.8	541.5–984.0
DXA FFM (kg)	23.9 ± 0.6	11.4–35.8
DXA fat mass (kg)	7.2 ± 0.8	1.1–39.3
DXA %fat (%)	20.1 ± 1.2	5.6–52.4
BIA equation FFM (kg)	24.0 ± 0.7	7.4–37.6
BIA equation fat mass (kg)	8.1 ± 0.7	1.2–38.5
BIA equation %fat (%)	23.2 ± 1.1	5.6–50.5

BIA, bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass.

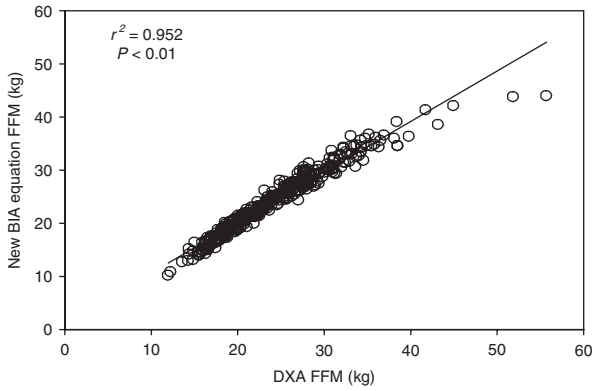

Figure 1 New BIA equation FFM vs. DXA FFM (n = 361). BIA, bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass.

Figure 2 shows the modified Bland–Altman plot for the subjects used to generate the new equation and demonstrates that 347 (of 361) or 96% of the measures fell within the 95% confidence intervals (−2.7 to 2.8 kg). The cross-validation analysis revealed that a significant amount (95.4%) of the variance in DXA FFM was explained by the new BIA equation (**Figure 3**). The FFM pure error of the cross-validation BIA sample calculated as the square root of the sum of the squared difference

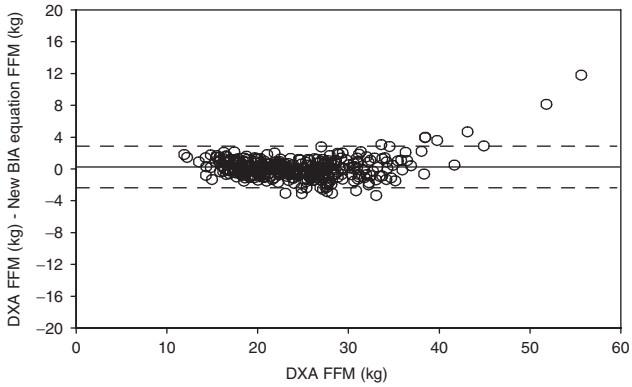

Figure 2 Modified Bland–Altman Plot: DXA FFM vs. new BIA equation FFM (n = 361). BIA, bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass.

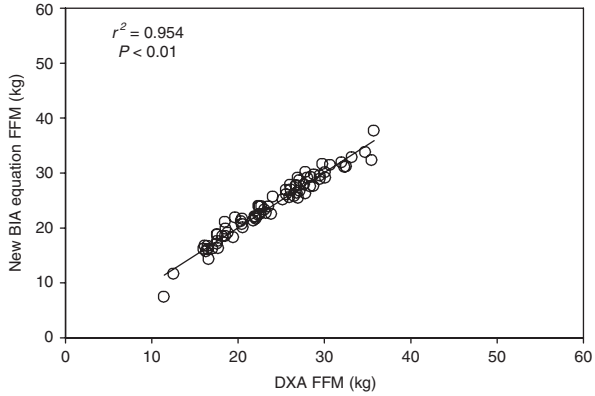

Figure 3 Cross-validation of new BIA equation FFM vs. DXA FFM (n = 75). BIA, bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass.

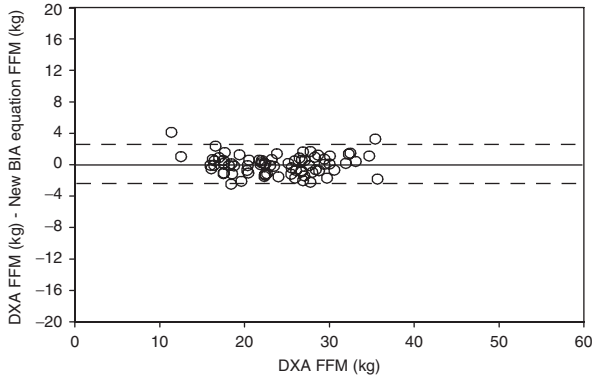

Figure 4 Modified Bland–Altman Plot: cross-validation DXA FFM vs. new BIA equation FFM (n = 75). BIA, bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass.

between the observed and predicted values divided by the number of subjects in the cross-validation sample was 1.2 kg. **Figure 4** shows the modified Bland–Altman plot for the subject used in the cross-validation analysis and demonstrated that 73 (of 75) or 97% of the measures fell within the 95% confidence intervals (−2.5 to 2.4 kg).

DISCUSSION

The primary purpose of this investigation was to provide a new and valid BIA equation to more accurately measure the body composition of young children of various sizes, including a representative sample of children that had a BMI for age and sex greater than the 85th percentile. The success of the newly validated equation can be shown by the large explained variance our original equation and by our cross-validation results. Typically, when a body composition equation is cross-validated, statistical shrinkage (a reduction of the explained variance) is expected. We did not observe statistical shrinkage and therefore this new equation can be used with a high degree of confidence in research, clinical, and field settings.

In addition, this investigation sought to provide a valid equation specifically for use in young children using an easy, safe, and economical method of determining body composition that can be used by those in all types of health settings. With the dramatic increase in childhood obesity, early intervention is important in the prevention and/or to combat obesity and its related metabolic, endocrine, and cardiovascular consequences (27). This newly developed pediatric specific BIA equation was developed in children of primary school age (grades kindergarten to 5th grade), a time in which children begin to have increased autonomy in their nutritional, physical activity, and other behavioral choices. With increasing trends of reduced physical activity levels as well as poor nutrition in children, the availability of an easily accessed and easily performed method of body composition so that the effectiveness of intervention strategies can be more accurately compared is critical in fighting this epidemic. Identifying the most effective intervention strategies may ultimately provide great assistance in the fight against the rising number of OB children.

We attempted to identify further explanations for the study findings. The results of this study and review of the modified Bland–Altman plots revealed that in a few of the children, the new BIA equation did not appear to work as well. It is important to suggest that the accuracy of the criterion FFM measure (DXA total body scans) may have been compromised due to the increased sagittal diameter of these individuals. It has previously been reported that the accuracy of the DXA soft-tissue measures can be reduced in individuals that have a sagittal diameter greater than 20 cm (28). While the scan mode was individually selected based on factors such as body weight and presumed sagittal diameter, we chose to use the adult analysis software because of the large number of children that exceeded the pediatric software analyses body mass maximum recommendation of ~36 kg, and to remain consistent in our analyses procedures. In addition, the subjects used to develop and cross-validate this new equation were all white non-Hispanic young children. Previous reports have indicated that race or ethnicity may be a factor that significantly impacts or influences resulting BIA equations (29,30) while others have found that ethnicity was not a significant predictive factor in resulting BIA prediction equations (31). While it may be speculated that population-specific ethnic factors may have a more significant influence on body composition when trying to measure or compare children during puberty and post puberty development, it has been previously reported that racial variations in body composition may begin in childhood (32). These differences have resulted in the suggested importance of using race-specific formulating in evaluating body composition (24). Future studies will determine the validity of using this equation for assessing body composition in young children of other ethnicities. In addition, we did not perform maturational assessments (Tanning Maturational Staging) for all our subjects and did not use maturational development as an inclusion or exclusion criterion because our goal was to provide an equation for use in a variety of primary school aged children. Furthermore, when we determined the explained variance of the FFM when the new equation was applied to the boys ($R^2 = 0.948$) and girls ($R^2 = 0.965$) separately, the predictive ability was not markedly altered. We believe this new equation will provide a valuable tool to help prevent and combat childhood obesity by providing a more valid measure of body composition and to allow a more accessible means of comparing the effectiveness of intervention strategies. The use and application of this new BIA equation for assessing body composition may also extended beyond its primary intent including that of determining medication dosing and assisting in rehabilitative patient care planning and progress monitoring.

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DISCLOSURE

The authors declared no conflict of interest.

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