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Validation of A Bioelectrical Impedance Analysis Equation for Predicting Body Composition in Young Children of Varying Ages and Ethnicities

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Abstract The purpose of this study is to determine if our previously published pediatric-specific bioelectrical impedance analysis (BIA) equation can successfully estimate body composition in 1) 5-11 year old, black, non-Hispanic and biracial children and in 2) children ages 2-4 years. A sample of 135 children (aged 5 to 11 years) was used for specific aim 1 while an additional sample of 47 children (aged 2 to 4 years) was used to assess specific aim 2. Dual energy X-ray absorptiometry (DXA) fat-free mass (FFM) was used as the criterion measure, and a single frequency tetra-polar BIA device was used within the pediatric-specific BIA equation. Our pediatric-specific BIA equation FFM explained 96.8% of the variance in DXA FFM within the 5-11 year old, black, non-Hispanic and biracial sample while explaining 94.1% of the variance in DXA FFM within the 2-4 year old sample. The use and application of our pediatric-specific BIA equation will provide a valuable tool to help prevent and combat childhood obesity by providing a method of assessing body composition that is considered valid, non-invasive, and economical and can be used in the laboratory, as well as a clinic or field setting.

Keywords: *body composition assessment, fat-free mass, pediatric, obesity, BIA prediction equation*

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1. Introduction

Current literature indicates the prevalence of obesity in the pediatric population has reached epidemic proportions in recent years. [1,2,3] Furthermore, obesity in children is often associated with unhealthy lifestyle leading to future risk of metabolic and cardiovascular diseases, decreased quality of life, and shortened lifespan. [4,5] Unhealthy nutritional intake, physical inactivity, and other deleterious lifestyle behaviors may result from various causes including but not limited to parental guidance, socio-economic and cultural diversity, access to proper nutrition, and education. [6] The CDC reports that the prevalence of obesity amongst children in the United States between the ages of 2 to 5 years is 1 in 7 while the prevalence of obesity in children ages 6 to 11 years is 1 in 5. [7] While these statistics are concerning, additional reports mention that the prevalence of childhood obesity is even higher amongst racial and/or ethnic minority children within the United States. [8,9] The CDC (2024) reports that childhood obesity is more prevalent among Hispanic (26.2%) and black, non-Hispanic (24.8%) children compared to white (16.6%) children. [10]

Given the strong association between obesity and cardiometabolic derangements that threaten the present and future quantity and quality of life, early intervention to prevent and combat obesity in young children is of the utmost importance. Moreover, one of the challenges of addressing obesity in young children is the ability to identify a valid, non-invasive, and economical method of assessing body composition that can be used in the laboratory, as well as a clinic or field setting. [11] While body mass index (BMI) is considered a simple measurement and a valuable tool in monitoring trends in obesity, BMI also has been known to have numerous disadvantages. [12,13] Specifically, BMI does not distinguish among the fat and fat-free masses (FFM; aqueous, mineral and protein) which may lead to significant misclassification and invalid results for obesity-based intervention strategies in many children. [11,12]

Bioelectrical impedance analysis (BIA) is considered a relatively inexpensive, non-invasive, and safe body composition technique that fulfills these methodological requirements; [11] however, there have been several reports questioning the accuracy of the predictive equations used to estimate body composition using BIA. [3,14,15] In addition, while there have been many BIA body composition prediction equations developed for a variety of children and adolescent populations, [16,17,18,19,20,21] many of these equations were developed when a greater percentage of the population was categorized as healthy weight (HW, BMI for age and sex between the 5th and 84th percentiles). [11] The lack of representation from other pediatric populations, including overweight (OW, BMI for age and sex between the 84th and 94th percentiles) and obese (OB, BMI for age and sex >95th percentile), as well as children of varying racial and ethnic backgrounds, may lead to inaccurately estimating body composition in a significant proportion of the pediatric population. [11]

Previously, our pediatric-focused laboratory created and cross-validated a pediatric-specific BIA equation in 5-11 year old white, non-Hispanic children. [11] The pediatric-specific BIA equation we provided was *DXA FFM (kg) = (-7,655 + 297 (Ht) + 125 (BMI) – 17.4 (Imp))/1,000* where Ht, standing height (cm); BM, body mass (kg); and Imp, BIA impedance (ohms). Our previously published BIA equation showed that 95.2% of the variance in DXA FFM was explained by our equation with a root mean square error of 1.4 kg. Furthermore, the cross-validation analysis revealed no statistical shrinkage with 95.4% of the variance in DXA FFM explained by our BIA equation. The FFM pure error of the cross-validation BIA sample, calculated as the square root of the sum of the squared difference between the observed and predicted values divided by the number of subjects in the cross-validation sample, was 1.2 kg. [11] While we demonstrated that we had created a valid BIA equation, our pediatric population was limited to white, non-Hispanic children of varying adiposities aged 5-11 years. Thus, we could not confidently assume that this equation would perform adequately when it was used to predict the FFM of children of different ethnicities or younger children. To date, we are unaware of any previous studies that have created a pediatric-specific BIA equation for use in 5-11 year old white, non-Hispanic and black, non-Hispanic children, and for use in 2-4 year old children. Therefore, the purpose of this study is to determine if our previously published pediatric-specific BIA equation is valid for use and can successfully estimate body composition in 1) 5-11 year old, black, non-Hispanic and biracial children and in 2) children ages 2-4 years.

2. Materials and Methods

2.1. Participants

A sample of 135 (55 males) children (aged 5 to 11 years), including 49 black, non-Hispanic males, 6 biracial males, 64 black, non-Hispanic females and 16 biracial females, was used for specific aim 1 while an additional sample of 47 (23 males) children (aged 2 to 4 years), including 1 biracial male, 1 black, non-Hispanic female, 2 biracial females, and the remaining 43 children identifying as white, non-Hispanic, was used to assess specific aim 2. We categorized participants who self-identified as biracial as children of parents from two different racial backgrounds. Prior to participation in this study, parental written informed consent and verbal assent were obtained for each participant in accordance with the policies and procedures of the University of Kentucky Office of Research Integrity (Lexington, KY). The study was reviewed and approved by the University of Kentucky Medical Institutional Review Board (IRB) to ensure that the design of this study protected the rights of the participants.

2.2. Anthropometric and Body Composition Measures

All subjects successfully completed anthropometric and body composition measures including standing height, weight, bioelectrical impedance analysis (BIA) measures, and a single, 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.

2.3. Standing Height and Body Mass

Participants' height and weight were determined using a calibrated electronic scale (Tanita Corporation; Model BWB-627A; Tokyo, Japan) and a wall-mounted stadiometer (Healthometer Professional; Model 597KLPELSTAR; Alspin, IL, USA). Standing height was measured with the subjects' hands positioned on the hips during a max inhalation and determined to the nearest 0.1 cm while body mass was determined to the nearest 0.01 kg.

2.4. Bioelectrical Impedance Analysis (BIA)

Each subject completed a BIA measurement performed using a tetra-polar device (Bodystat Quadscan 4000; Bodystat; Isle of Man, British Isles). All subjects were instructed to lie supine on a nonconductive, padded table while sensor surface electrodes were placed on the right wrist (at the midpoint of the head of the ulna) and the right ankle (at the midpoint of the medial and lateral malleoli), and source surface electrodes were placed on the right hand and foot at the base of the metacarpal-phalangeal and metatarsal-phalangeal joints, respectively. Multiple frequencies (5, 50, 100, and 200 kHz) were introduced through the source electrodes and the resulting impedance measure at 50 kHz was used for further analyses. The BIA procedure was performed twice consecutively, and the mean of the resulting impedance measures was used for subsequent analyses.

2.5. Dual Energy X-ray Absorptiometry (DXA)

A single total-body DXA scan was performed for all subjects. A Lunar DPX-IQ bone densitometer (GE Lunar; Madison, WI, USA; software version 4.7) was used for the 5-11 year old, white, non-Hispanic and black, non-Hispanic and biracial subjects while a Lunar Prodigy (GE Lunar; Madison, WI, USA; software version 4.7) was used for the 2-4 year old subjects. Prior to scanning, all subjects were instructed to remove all metal including eyeglasses and jewelry. A single trained investigator analyzed all DXA scans to determine total body DXA FFM (kg) for each participant.

2.6. Statistical Methods

For the 5-11 year old, black, non-Hispanic and biracial sample (n = 135) and the 2-4 year old sample (n = 47), means, standard deviations (SD), and ranges for age, height, weight, body mass index (BMI), BMI percentile, DXA FFM, and BIA equation FFM were determined. BMI was calculated as weight in kilograms divided by height in meters squared. To determine BMI percentile, each participant's BMI was examined against CDC growth charts for age and sex. [7] The pure error, calculated as the square root of the sum of the squared difference between the observed and predicted values divided by the number of subjects in the cross-validation sample, was determined for both samples using the DXA FFM and BIA equation FFM while correlational analyses were used to determine the association between the DXA FFM and the BIA equation FFM. An additional correlational analysis was used to determine the association between DXA FFM and the BIA equation FFM within the 5-11 year old, black, non-Hispanic and biracial sample, the 2-4 year old sample, and the sample from our previous work (5-11 year old, white, non-Hispanic children). [11] Lastly, modified (DXA criterion measure used alone on x-axis) Bland-Altman [22] plotting was used to visually assess agreement and graphically demonstrate the mean differences and the 95% confidence intervals between the DXA FFM and the BIA equation FFM for both samples.

3. Results

Demographic and descriptive characteristics for the 5-11 year old, black, non-Hispanic and biracial sample and for the 2-4 year old sample are presented in Table 1. The pure error was 1.5 kg and 2.2 kg for the 5-11 year old, black, non-Hispanic and biracial sample and the 2-4 year old sample, respectively.

Table 1. Characteristics of study participants

	Black, non-Hispanic Sample (N=135)		2-4 Year Old Sample (N=47)	
	Mean ± SD	Range	Mean ± SD	Range
Age (yrs)	8.5 ± 2.0	5.1-11.9	3.6 ± 1.0	2.1-4.9
Height (cm)	133.4 ± 14.4	105-167.5	100.7 ± 8.7	85.5-122.9
Weight (kg)	35.5 ± 15.3	17.5-116.8	16.7 ± 3.4	11.5-28.9
BMI (kg.m^2)	19.2 ± 4.8	12.9-44.1	16.4 ± 1.5	13.3-21.3
BMI Percentile	70.0 ± 27.6	0.9-99.8	60.9 ± 27.2	1.0-99.0
DXA FFM (kg)	25.5 ± 7.2	14.6-51.2	13.3 ± 2.5	9.5-21.2
BIA FFM (kg)	24.6 ± 6.8	13.0-47.2	11.4 ± 3.5	6.5-20.9

Abbreviations: Body Mass Index (BMI); Dual X-ray Absorptiometry (DXA); Bioelectrical Impedance Analysis (BIA); Fat-Free Mass (FFM)

The BIA equation FFM explained 96.8% of the variance in DXA FFM within the 5-11 year old, black, non-Hispanic and biracial sample (Figure 1A) while the BIA equation FFM explained 94.1% of the variance in DXA FFM within the 2-4 year old sample (Figure 1B).

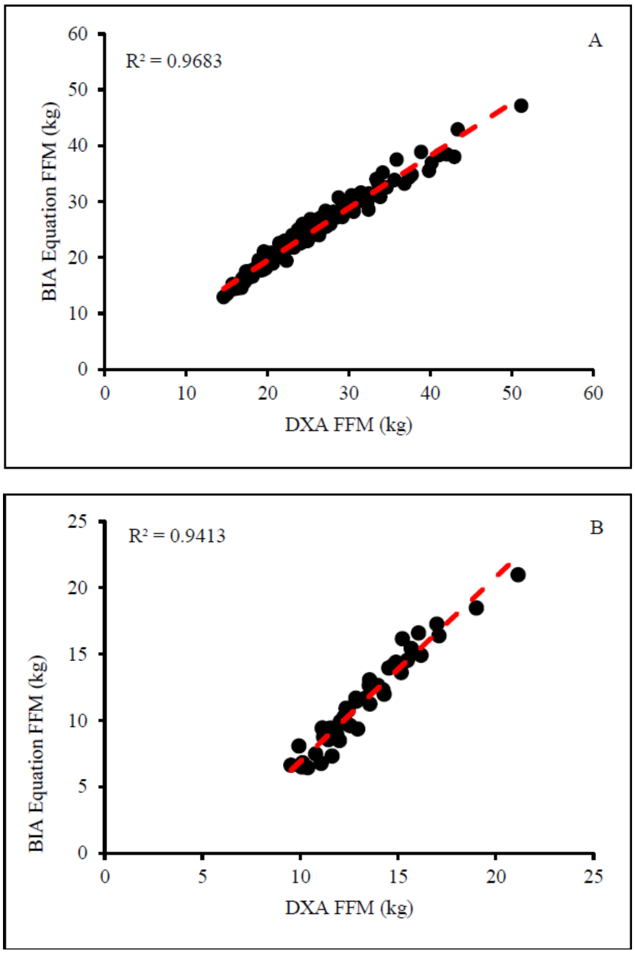

Figure 1. Associations between DXA FFM and BIA Equation FFM for (A) 5-11 year old, black, non-Hispanic and biracial sample and (B) 2-4 year old sample

Similarly, when analyzing the association between the DXA FFM and the BIA equation FFM within the 5-11 year old, black, non-Hispanic and biracial sample, the 2-4 year old sample, and the white non-Hispanic 5-11 year old sample from our previous work [11] (Figure 2; n=543), the BIA equation FFM explained 95.2% of the variance in DXA FFM.

Bland-Altman plotting was used to visually assess agreement and graphically demonstrate the mean difference and the limits of agreement (±2 SD) between the DXA FFM and the BIA equation FFM for the black, non-Hispanic, 5-11 year old sample (0.87 ± 1.3 kg) (Figure 3A), and for the 2-4 year old sample (1.84 ± 1.28 kg) (Figure 3B). In addition, Bland-Altman plotting demonstrated that there was no significant systematic (directional) bias for the 5-11 year old, black, non-Hispanic and biracial sample. In contrast, the Bland-Altman plot for the 2-4 year old sample indicated significant systematic (directional) bias (demonstrated by significant association of Bland-Altman plot variables) suggesting that as the average FFM increases, the BIA equation increasingly underestimates FFM relative to DXA.

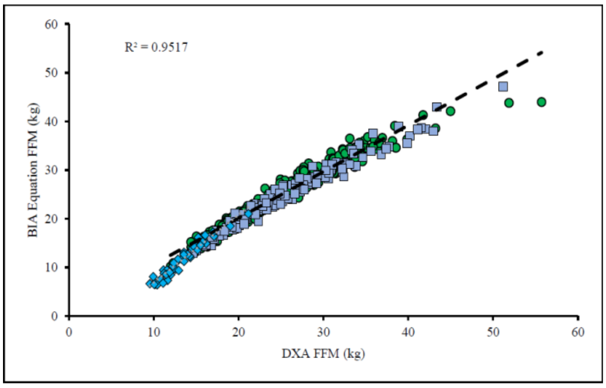

Figure 2. Association between DXA FFM and BIA Equation FFM for 5-11 year old, black, non-Hispanic and biracial sample,2-4 year old sample, and Clasey et al. 2011 sample

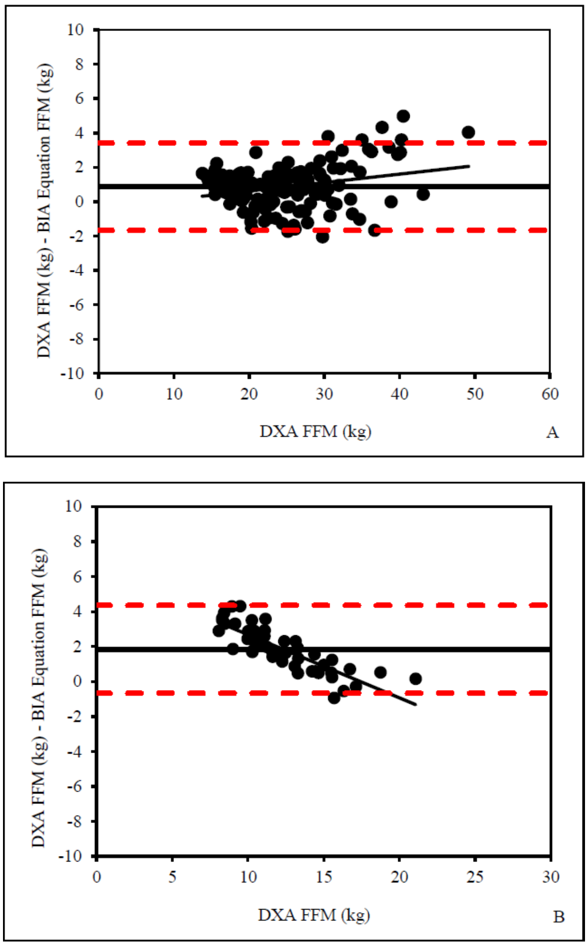

Figure 3. Bland-Altman plots for (A) 5-11 year old, black, non-Hispanic and biracial sample and (B) 2-4 year old sample

4. Discussion

We have previously determined that our pediatric-specific BIA equation [11] is valid for use and can successfully estimate body composition in 5-11 year old white, non-Hispanic children. To date, there have been few studies that have created and cross-validated a new BIA equation for estimating body composition in young children of varying ages and ethnicities. [16,23,24] [25,26,27,28] The current study is the first to report these findings separately and jointly for 5-11 year old, black, non-Hispanic and biracial children and for children ages 2-4 years.

Our pediatric-specific BIA equation was originally developed in 5-11 year old white, non-Hispanic children. The successful use of our pediatric-specific BIA equation in the 5-11 year old, black, non-Hispanic and biracial sample and the 2-4 year old sample is best demonstrated by the significant and large explained variances. [21] Both samples demonstrated excellent explained variance of 96.8% and 94.1% for the 5-11 year old, black, non-Hispanic and biracial sample and the 2-4 year old sample, respectively. In addition, the pure error was 1.5 kg and 2.2 kg for the 5-11 year old, black, non-Hispanic and biracial sample and the 2-4 year old sample, respectively. We believe that the larger pure error of the 2-4 year old cohort is likely due to the influence of a smaller range of standing heights. According to the principles of BIA methodology, the resistance of current flow is proportional to the length of the conductor, thus making standing height a primary predictor variable. [29] Furthermore, the larger pure error of the 2-4 year old cohort may also be attributed to the smaller ranges of FFM and the small number of participants of this cohort.

While age is a major factor influencing changes in body composition [30,31,32], other reports have indicated that race or ethnicity is also an important factor when determining body composition. [8,33,34,35] Furthermore, several reports have indicated that race or ethnicity is a fundamental consideration in resulting BIA equations; [36,37] however, others have concluded that race or ethnicity was not considered a significant predictive factor when establishing BIA prediction equations. [38] These reported discrepancies have resulted in the suggested use of race-specific BIA prediction equations or selecting a more appropriate method to accurately assess body composition for specific racial/ethnic populations. [39]

The results of our Bland-Altman [22] analyses demonstrated that there was no significant systematic (directional) bias for the 5-11 year old, black, non-Hispanic and biracial sample while significant systematic (directional) bias was demonstrated for the 2-4 year old sample. This result suggests that as the average of the measures increases, the difference between the two measures becomes progressively more negative for the DXA FFM mean. Furthermore, the findings from our Bland-Altman analyses are specific to the population studied (younger children of varying adiposities and ethnicities); thus, these results may not be generalizable to other populations.

A limitation of this study was the use of two different DXA machines. A Lunar DPX-IQ bone densitometer (GE Lunar; Madison, WI, USA; software version 4.7) was used for the 5-11 year old, white, non-Hispanic and black, non-Hispanic and biracial subjects while a Lunar Prodigy (GE Lunar; Madison, WI, USA; software version 4.7) was used for the 2-4 year old subjects. Due to the timeline at which the data for this study was collected, and due to advancements in DXA scanning instruments and software, we believe the use of two different DXA machines within this study is validated. An additional limitation of this study was the absence of a formal maturational assessment. An objective of this study was to provide an equation that was generalizable to a variety of young populations including age and ethnicity. We believe employing a formal maturational assessment could limit the validity of our pediatric-specific equation and reduce the equation's practical utility.

5. Conclusion

Our original goal for creating and cross-validating a new BIA equation, that included children of varying adiposities, was to aid in preventing and combating childhood obesity and to provide a tool for medication dosing and assisting in rehabilitative patient care planning and progress monitoring. Based on the results of this study we can confidently determine that our previously published pediatric-specific BIA equation is valid for use and can successfully estimate body composition in 5-11 year old, black, non-Hispanic and biracial children and in children ages 2-4 years. Future studies should determine the validity of using this equation for assessing body composition in young children of additional ethnicities. Maturational assessments (Tanner Maturational Staging) were not performed for all of our subjects, and we did not use maturational development as inclusion or exclusion criteria as an additional objective of this study was to provide an equation for use in variety of school-aged children. The use and application of our pediatric-specific BIA equation will provide a valuable tool to help prevent and combat childhood obesity by providing a method of assessing body composition that is considered non-invasive, economical, and usable in the laboratory, as well as a clinic or field setting. Specifically, the use of our equation would aid in individualized body composition assessment for baseline and progressive measures during weight loss programs to help more accurately monitor change, medication and chemotherapy dosing, and to accurately evaluate an indiviudals basal metabolic rate (BMR) and fitness levels.

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Statement of Competing Interests

The authors have no competing interests.

List of Abbreviations

BIA, bioelectrical impedance analysis; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass; HW, healthy weight; OW, overweight; OB, obese

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