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Ethnic Variation in Body Composition Assessment in a Sample of Adolescent Girls

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Abstract

Objective—To examine whether bioelectrical impedance analysis (BIA) is a valid measure of body composition in a multiethnic sample of adolescent girls, as compared to dual-energy X-ray absorptiometry (DXA).

Method—Data were from a physical activity intervention study among 276 14–20 year-old sedentary American girls, including 74 whites, 85 blacks, 46 Hispanics, and 71 Asians. Height and weight were objectively measured. Body composition was assessed using a foot-to-foot BIA and a fan-beam DXA. Linear regression models quantified baseline cross-sectional estimates of percent body fat, fat mass, fat-free mass, fat mass index, and fat-free mass index and their BIA-DXA differences, which we considered an estimate of bias. Variation in BIA-DXA by ethnicity and DXA-assessed adiposity was examined with tests of statistical interaction.

Results—Compared to DXA measurement, BIA significantly underestimated percent body fat, fat mass, and fat mass index, and overestimated fat-free mass and fat-free mass index in each ethnic group. There was significant ethnic variation in BIA-DXA bias: percent body fat was underestimated by between 4.8% in blacks and 8.6% in Asians (p-value, interaction<0.001), as were fat mass (p-value=0.012) and fat mass index (p-value<0.001); fat-free mass index was overestimated (p-value=0.002). The degree of ethnic-specific bias varied according to DXA-assessed body composition values. For example, there was relatively greater ethnic variation in bias estimating percent body fat at lower DXA-assessed percent body fat values.

Conclusion—Compared to DXA, BIA underestimated measures of adiposity in a multiethnic adolescent sample. Further, BIA-DXA bias varied by ethnicity and across measures of adiposity.

Keywords

Bioelectrical impedance; dual-energy X-ray absorptiometry; ethnicity; race adiposity; body composition; female; adolescent

Introduction

Limitations of the body mass index (BMI) in distinguishing fat and fat-free mass have lead clinicians and researchers to seek alternative methods. Bioelectric impedance analysis (BIA) has gained in popularity for this purpose because it is easy to use, safe, portable, inexpensive, and acceptable to populations[1]. These attributes make BIA especially attractive

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as an option for body composition assessment in the clinical setting or for data collection in the field[2–3].

Despite the many appealing features of BIA, its accuracy in assessing body fat remains unclear[4–8]. Further, there is evidence that differences in accuracy may exist among ethnic groups[6, 9–11], and perhaps additionally across the range of adiposity[12]. Determining the validity of BIA is significant given the growing use of BIA in scientific studies; understanding ethnic differences in the assessment of body composition is particularly important given the clear ethnic disparities in adolescent and adult chronic disease risk factors, including overweight[13].

The accuracy of BIA is dependent on the equations that use directly-assessed bioelectric measures (e.g., impedance, resistance) to estimate total body water, which is then used to estimate fat free mass. BIA equipment often includes programmed equations that provide parameter estimates, such as percent body fat. The validity of these equations can be sensitive to personal characteristics, and programmed BIA equations will not apply to all populations. Using data from BIA and a laboratory standard, such as dual-energy X-ray absorptiometry (DXA), investigators have created equations that provide valid body composition estimates in their sample, using BIA data and individual characteristics, such as age, sex, ethnicity, height, and weight[6, 14]. Ideally, these equations could be used by other study investigators to adjust or interpret BIA data without the need to employ resource-intensive methods such as DXA to create their own validation equations. However, the studies in which these equations have been developed vary greatly with respect to sample characteristics, BIA methods, and the standard employed, and the ability of such equations to provide accurate adjusted estimates in other samples has not been established.

Using data from a physical activity intervention study in a multiethnic sample of adolescent girls (New Moves)[15], we examined whether: 1) BIA provided valid estimates of several body composition variables, as compared to DXA); 2) there were ethnic differences in BIA bias in body composition assessment; 3) any ethnic differences in BIA bias varied across adiposity level; and 4) previously-published equations yielded accurate BIA-adjusted estimates of percent body fat in our sample.

Methods and Procedures

Study design and sample

Data were from a group-randomized intervention study to evaluate New Moves, a school-based obesity-prevention physical education program[16] conducted in six intervention and six control high schools in the Minneapolis/St. Paul metropolitan area (Minnesota, USA) during the 2007–2009 school years. The study was approved by the University of Minnesota’s Institutional Review Board and by participating school districts. Participants provided written assent and parental consent.

Girls (n=356) were recruited into the study during the spring and fall prior to study implementation. Girls in both intervention and control schools were invited to register for an all-girls physical education class as an alternative to the regular co-educational physical education class, and received credit towards their physical education requirement[15]. Recruitment materials were designed to attract girls who were inactive, felt uncomfortable in regular physical education classes, and were interested in learning about healthy weight management. Compared to national and state surveillance data, New Moves girls had higher BMIs than same-age girls in the United States or Minnesota.

We excluded study participants who were missing data for BIA and BMI (n=1) or DXA (n=44) and 35 youth who reported Native American or mixed ethnicity. After exclusions, there were data for 276 study participants available for analysis.

Data collection and measures

Data were collected at the University of Minnesota's General Clinical Research Center by trained study staff. Study participants completed a written survey that queried aspects of diet, physical activity, other weight-related behaviors and attitudes, and demographics, such as Ethnicity, U.S. nativity, and background. Physical activity was assessed with the 3-Day Physical Activity Recall (3-DPAR) survey[17], which assesses various activities in blocks of 30 minutes.

Ethnicity was assessed at baseline with the question: "Do you think of yourself as: 1) white, 2) black or African American, 3) Asian, 4) Native Hawaiian or Other Pacific Islander, 5) American Indian or Alaskan Native, 6) Hispanic or Latina, 7) other." Girls could choose more than one category. If two ethnicities were selected and one was white, the variable was coded as the non-white ethnicity. If two non-white ethnicities or more than two ethnicities were selected the participant was considered mixed ethnicity. Participants were asked if their background included any of the following: Hmong, Cambodian, Vietnamese, Laotian, Somali, or Ethiopian, which represent major immigrant populations in the Minneapolis/St. Paul area. Space was also included on the survey for girls to write in a heritage background not included on the list. For the analyses, responses were combined into four ethnic groups: white, black, Hispanic, and Asian. Those who specified American Indian (n=9) or mixed ethnicity (n=26) were excluded because of the small sample sizes and to aid interpretation of results.

Physical measurements included height, weight, DXA, and BIA. Participants wore light clothes and were measured in bare feet. Height was measured to the nearest 0.1 centimeter with a portable stadiometer (Perspective Enterprises, Portage MI). A Tanita Body Composition Analyzer TBF-300A, a 50 kHz leg-to-leg BIA system (Tanita Corporation of America, Arlington Heights, IL), was used to measure weight and percent body fat. For all BIA measurements, a deduction of 0.5 kg for clothes was taken and all measurements were done using the standard, rather than athletic, body type mode. Weight was measured to the nearest 0.1 kilogram (Tanita Corporation of America, Arlington Heights, IL). Weight, height, and BIA measurements were taken twice during the same clinic visit and averaged for analysis. We calculated body mass index (BMI) as weight (kg)/height$(m)^2$. Female BMI-for-age percentiles and BMI-for-age z-scores were calculated from the CDC 2000 growth charts[18]. Using BMI percentiles, we classified participants as non-overweight ($<85^{th}$), overweight ($\geq 85^{th}$ and $<95^{th}$) or obese ($\geq 95^{th}$)[19].

Fat mass (FM) and fat-free mass (FFM) were assessed by trained and certified medical assistants using a whole-body, fan-beam DXA scanner (Lunar Prodigy, Madison, WI; Encore 2005, version 9.3 software). Girls who were found to be pregnant by a urine pregnancy test or who refused the urine test were excluded. Percent body fat was calculated as fat mass (kg)/(fat mass (kg) + fat-free mass (kg)). Fat mass index and fat-free mass index were calculated, respectively, as: fat mass (kg)/height $(m)^2$ and fat-free mass (kg)/height $(m)^2$.

Statistical analysis

We obtained total-sample and ethnicity-specific means of body composition variables from DXA and BIA and their differences (BIA-DXA) as least square means from general linear regression models. Statistical interactions of ethnicity with body composition measures and

BIA-DXA bias were similarly evaluated. All regression models were adjusted for median-centered age (median=184 months). It was not necessary to include intervention condition in the models because the analyses were conducted on baseline data collected before schools were randomized to condition. To allow visual inspection and presentation of the ethnicity-specific relations, we fit cubic splines using a SAS macro by Harrell[20] implementing the method of Stone and Koo[21], using 4 knots at the 5th, 25th, 75th, and 95th percentiles of the distributions of the age-standardized BMI or DXA-assessed body composition measures.

Finally, we compared our BIA bias estimates to corresponding estimates calculated after "adjusting" BIA data as proposed in four previously-published equations from studies in adolescent samples. For inclusion in our comparisons, equations had to be derived from female-only samples or have included a term for gender, use impedance—rather than resistance, and not have included other variables unavailable in New Moves, e.g., skinfolds. Equations provided adjusted estimates for FFM or total body water (TBW). Our BIA assumed TBW to equal 73% of FFM. We calculated percent body fat from corrected FFM estimates by dividing FFM by total weight, subtracting the result from 1, and multiplying by 100.

All analyses were conducted on baseline data using SAS (PC version 9.2). Statistical significance was based on an alpha ≤ 0.05.

Results

Characteristics of study sample

Table 1 displays unadjusted summaries of demographic, size, and body composition data for the study sample. The sample was diverse with respect to ethnicity (26.8% white, 30.8% black, 16.7% Hispanic, and 25.7% Asian). A fairly large percentage of total participants reported having been born outside of the U.S. (31.5%), with Hispanic youth having the single greatest proportion (63%). Ninety percent of Asians reported Hmong ethnicity, and 32% of blacks reported East African background (data not shown). The study sample ranged in age from 14 to 20 years, with the majority (56.9%) 14 or 15 years. There were no significant differences among the ethnic groups in mean age. Asian youth tended to be shorter and lighter than youth in the other ethnicity categories although there were no significant differences among the groups in mean BMI. Blacks had the highest percentages of overweight and obesity (49.4%, 32.9%), while Asians had the lowest (36.6%, 16.9%), though these differences did not attain statistical significance when considered across all groups. Moderate and vigorous physical activity varied significantly by ethnicity (p-value=0.012), with black girls reporting the lowest levels.

Correlations among body composition measures

Age- and ethnicity-adjusted correlation coefficients among body composition measures revealed strong (r≥0.80) correlations between DXA and BIA measurement of percent body fat, fat mass, and fat mass index, and between fat free mass and fat free mass index (table 2). Analyses stratified by ethnicity revealed significant ethnic differences in correlations. Compared to other ethnicities, white girls tended to have higher correlations among percent body fat and fat mass (FM) measures. The correlations between DXA- and BIA-assessed percent body fat were close, ranging from 0.87 in Hispanics to 0.94 in whites, but statistically significantly different.

Ethnic differences in body composition estimates from DXA and BIA

The average percent body fat, according to DXA, in the study sample was 36.9% (table 3). Mean DXA-assessed percent body fat estimates differed by ethnicity: 36.5% (SE=1.1) in

whites, 39.1%(1.0) in blacks, 37.1%(1.4) in Hispanics, and 34.8%(1.1) in Asians. Significant ethnic differences were also observed for other DXA- and BIA-assessed body composition measures.

BIA bias in body composition assessment and ethnic differences in bias

BIA bias (BIA-DXA) was statistically significant for every body composition measure studied, and for every ethnic group. BIA underestimated percent body fat, fat mass, and fat mass index, and overestimated fat-free mass and fat-free mass index (table 3). Further, significant ethnic differences were observed in the BIA-DXA bias in body composition assessment. BIA underestimated DXA percent body fat by 6.0% (SE=0.49) in whites, 4.8%(0.46) in blacks, 6.1%(0.63) in Hispanics, and 8.6%(0.50) in Asians; underestimated fat mass by between 2.9 kg (blacks) to 4.3 kg (Asians); and consequently overestimated fat-free mass by between 3.3 kg in blacks to 4.5 kg in Asians. In general, the greatest bias was observed in Asians and the smallest in blacks. In Asians, BIA yielded greater underestimates of percent body fat (−8.6%), fat mass (−4.3 kg), and fat mass index (−1.9 kg/m^2) and greater overestimates of fat free mass (4.5 kg) and fat-free mass index (2.0 kg/m^2). Among blacks, BIA provided the smallest underestimates of fat mass (−2.9 kg) and fat mass index (−1.1 kg/m^2) and the smallest overestimate of fat-free mass index (2.0 kg/m^2). Bias estimates for whites and Hispanics were between those for Asians and blacks. Similar patterns of bias across ethnic groups were observed when we defined bias as the BIA/DXA ratio rather than the difference (data not shown).

We considered that there might be variability in body composition measures and in BIA-DXA bias when comparing girls with East African background to other black girls. In an age-adjusted linear regression analysis restricted to black girls, East African girls had lower mean fat mass (21.1 vs. 33.1 kg), fat-free mass (33.5 vs. 45.4 kg), fat mass index (8.2 vs. 12.5 kg/m^2), and fat-free mass index (13.2 vs. 17.2 kg/m^2) than other black girls. East African girls had higher levels of BIA-DXA bias for all body composition measures, compared to other (non-East African) black girls (data not shown).

Ethnic differences in the patterns of BIA bias across the range of DXA-assessed body composition measures

We next examined the degree of bias across the distribution of DXA-assessed body composition. Overall, the BIA-DXA bias in percent body fat was smallest at the lowest DXA-assessed percent body fat levels in the sample (bias = −3.0% at 15% body fat) and greatest at 40% body fat (−6.7%) (data not shown). However, the pattern of BIA-DXA bias in percent body fat across the distribution of DXA-assessed percent body fat varied significantly by ethnicity (figure 1.a.; p-value for interaction=0.016). Significant ethnic variation was also observed in the pattern of BIA-DXA bias in fat mass index across the distribution of DXA-assessed fat mass index (figure 1.b.; p-value for interaction<0.001), and in the patterns of BIA-DXA bias in fat mass, fat-free mass, and fat-free mass index over their respective DXA-assessed distributions (data not shown).

BIA bias adjustment using previously-published equations

Finally, we corrected BIA estimates using four previously-published equations and recalculated the bias estimates for percent body fat. Bias estimates based on three of the four equations were as large as estimates from original, uncorrected New Moves's BIA data, even when restricted to the ethnic group(s) included in the studies from which equations were derived (table 4). However, improved estimates were obtained from an equation based on a U.S. sample of black girls[22], aged 8–10, measured with similar BIA and DXA methods as the girls in New Moves. Compared to New Moves bias estimates of −6.0 (total sample),

−5.9 (whites), −4.9 (blacks), −6.4 (Hispanics), and −8.5 (Asians), corrected bias estimates were, respectively, −1.7, −1.2, −0.45, −1.8, and −3.6 (table 4).

Discussion

In this sample of adolescent girls, BIA estimates of body composition were significantly biased, when compared to DXA estimates: measures of body fat were underestimated and measures of lean tissue were overestimated. Ethnic differences were apparent in the validity of body composition assessment by BIA. Further, the patterns of ethnic differences in BIA bias varied significantly across the distribution of other body composition measures. Previously-published BIA-adjustment equations did not generally yield estimates that improved upon our BIA-assessed estimates, except for the equation from a U.S. sample of black girls[22].

Over the past decade BIA has gained in acceptance, and is increasingly used in research and surveillance to assess body fat percent[1]. BIA has many practical attributes, and has been promoted as a more accurate measure of body fat than BMI[23–24] and a viable alternative to DXA[4]. However, consistent with our findings, researchers have also reported significant underestimates of percent body fat from BIA, compared with DXA[5–8], ethnic differences in BIA bias[3, 6, 9–11], and evidence that ethnic differences vary across values of BMI-for-age[12].

Previous reports of ethnic differences in BIA accuracy[3, 6, 9–11] lack consistency with respect to the extent or direction of bias. As an example, compare our data, in which BIA underestimated percent body fat in all ethnic groups, to data from a physical activity trial in which body fat percent was underestimated in white and Hispanic girls, but overestimated in black girls[10]. Differences in BIA bias across studies may relate to differences in individual characteristics of the samples or in assessment equipment[25]. In any event, the literature points to ethnic-specific biases, and the lack of consistency across studies further complicates efforts to interpret estimates.

Differential BIA accuracy across the range of body composition assessed by a reference standard—a possibility long-considered[26], with fatness-specific BIA equations published in 1988[27] — has received recent interest in the literature[6]. In adult and pediatric samples of various ethnic compositions, BIA has overestimated percent body fat among participants with less body fat and underestimated percent body fat among participants with more body fat[3, 6, 28–31]. Investigators reported that this pattern of BIA bias across values of percent body fat was observed in both girls and boys and within all ethnic groups[3, 6]. In contrast, we found this pattern among blacks and Hispanics only, in whom BIA overestimated percent body fat at the lowest levels of DXA-assessed percent fat (15–20% body fat); among whites and Asians, BIA underestimated percent body fat at all values of DXA-assessed percent body fat. Notably, bias patterns differed for percent body fat and fat mass index, with greater bias, and greater ethnic variation in bias, at lower percent body fat values, but higher fat mass index values.

The accuracy of BIA is dependent on the equation used to estimate total body water from impedance. Investigators have improved on BIA estimates by creating equations that account for personal characteristics of their sample—such as age, sex, ethnicity, height, and weight[6, 22]. Ideally, published equations could be used by study investigators, who have only BIA data, to improve the accuracy of their body composition estimates. However, given the sensitivity of BIA to personal characteristics, which varies across studies, this may prove challenging in practice.

We examined four impedance-based equations from studies in adolescent samples, estimates from three of which did not improve upon New Moves BIA estimates, even when matched

on ethnicity. Similarly, Loftin et al. reported that none of seven tested equations provided sufficiently valid estimates of percent body fat[3]. The study samples differed with respect to age and nationality (mostly non-U.S.), as well as in the comparison methods to which BIA data to adjusted and in equipment. These differences appear to be significant, as the one equation that provided improved bias estimates was derived from a U.S. sample of black girls who were measured with the same BIA (Tanita 300) as the New Moves sample, using DXA as the comparison. These findings suggest that BIA bias may often be difficult to correct using published equations, given variability in equipment and sample characteristics. In addition, our equations only comprise those that used impedance, since resistance data were not available.

Our study has strengths and caveats that deserve mention. Our sample of female adolescents was relatively large and ethnically-diverse. Although other studies may have larger total sample sizes, these studies also generally include both sexes and have a broader age range—both of which contribute to variations in body composition and its assessment. Furthermore, that our results were statistically significant demonstrates sufficient power to test studied associations. Still, ethnic-specific numbers were small, especially when examining patterns of bias across body composition values, and confirmation in larger samples is needed.

The distribution of percent body fat in our sample was higher than in a national U.S. sample of adolescent girls[32] as well as in some[22], but not all[6], previous studies of BIA bias. Thus, our findings may not be generalizable. However, our sample was selected as being particularly at-risk for future obesity, and reflects a population of interest for many weight-related public health interventions. Further, despite the higher mean adiposity in our sample, the variability of adiposity did not appear lower than other samples of adolescent body composition[12].

We used DXA as our comparison standard, though DXA itself can yield biased estimates of fat mass, when compared with 4-compartment models[33–35]. We know of no study that has validated the Lunar Prodigy fan-beam DXA scanner in a multiethnic sample of adolescent girls. Perhaps most relevant is a validation of percent body fat estimates from a pencil-beam (Hologic) DXA and a 4-component model in a multiethnic sample of adolescent girls[34]. This study found that DXA overestimated percent body fat by 3.9, but that bias did not vary by ethnicity or adiposity[34]. Given differences in equipment[33], we cannot assume that the 3.9% applies to our data, but the lack of differential bias across ethnicity or adiposity suggests that DXA bias would not explain the variation that we observed in BIA-DXA according to ethnicity and adiposity.

In conclusion, our findings revealed significant BIA bias in the assessment of body composition measures, as compared to DXA. In addition, we found that BIA bias varied by ethnicity and according to adiposity. Measurement bias was not resolved in our study by using published adjustment equations. The fact that BIA bias was differential and jointly-related to ethnicity and body fatness underscores the importance of considering distributions of both when interpreting study findings. Additional research in this area is needed to better understand relations between body composition and ethnicity, and to identify valid options for the assessment of body composition that are also affordable and easy to use.

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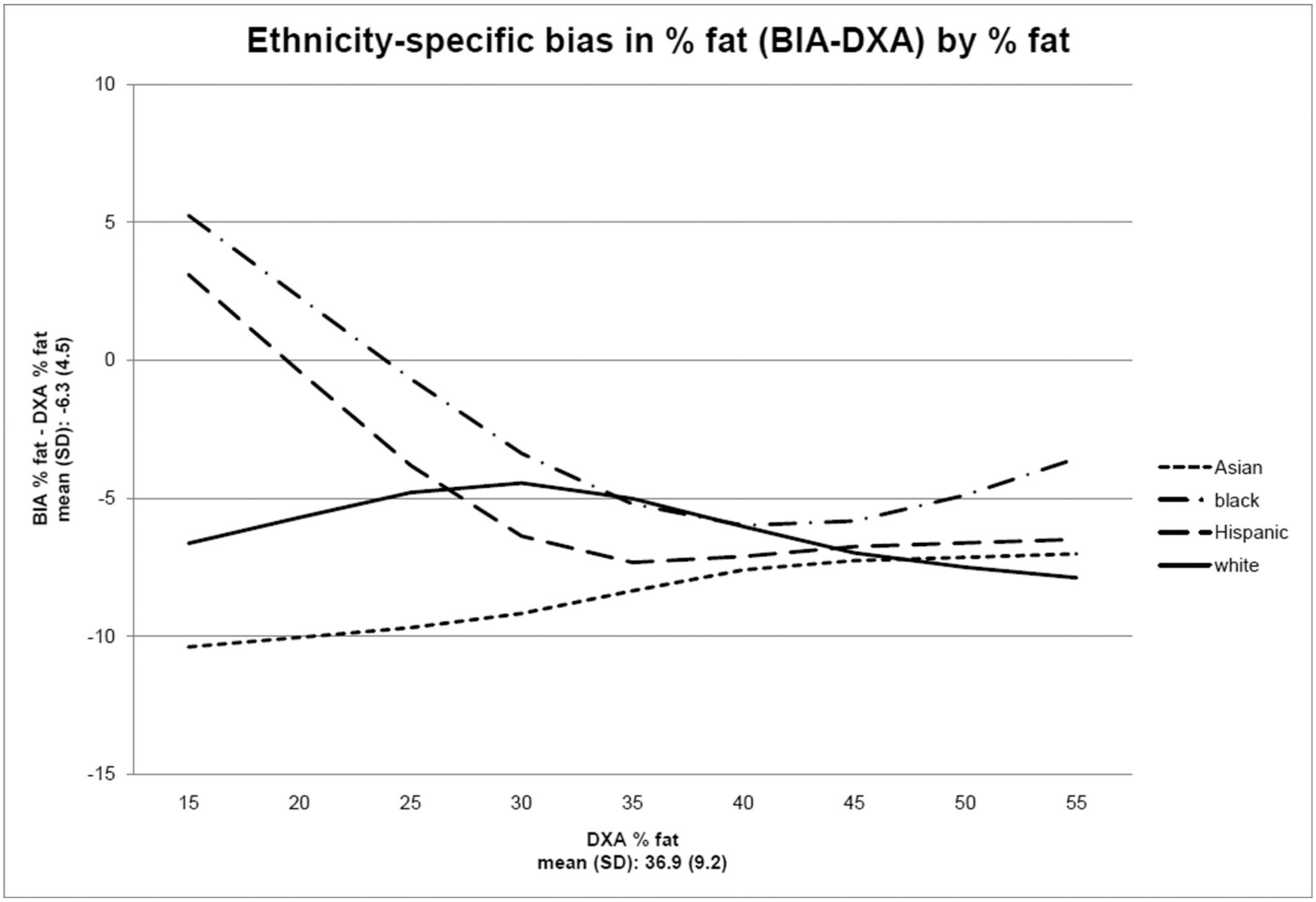

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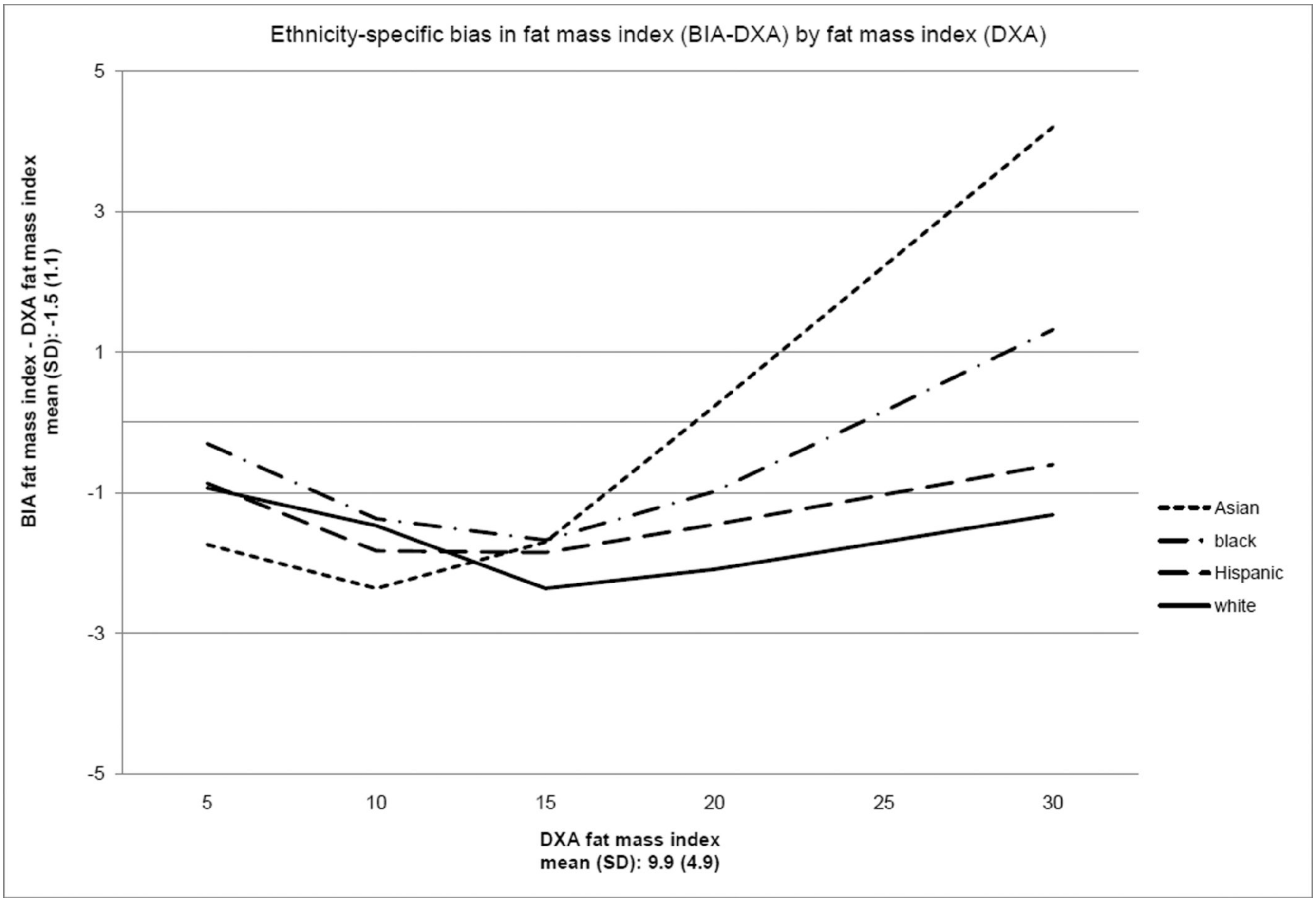

Figure 1.

Spline-smoothed ethnicity-specific associations between BIA bias in percent body fat and DXA-assessed percent body fat and between BIA bias in fat mass index and DXA-assessed fat mass index. P-values are tests for statistical interaction.

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Table 1

Baseline characteristics of study participants by ethnicity[a].

	Total	White	Black	Hispanic	Asian	P-value[b]
n (%)	276	74 (26.8%)	85 (30.8%)	46 (16.7%)	71 (25.7%)	
Age (months)	188.3 (14.1)[c]	186.3 (11.9)	189.3 (16.4)	191.7 (17.1)	186.9 (10.9)	0.16
Not born in U.S.	31.5 (2.8)	5.4 (2.7)	34.1 (5.2)	63.0 (7.2)	35.2 (5.7)	<0.001
Anthropometry						
Height (cm)	158.2 (5.8)	161.8 (5.7)	161.2 (6.1)	156.5 (6.3)	151.8 (5.1)	<0.001
Weight (kg)	64.4 (18.9)	66.2 (16.4)	71.3 (23.4)	61.3 (16.5)	56.2 (16.3)	<0.001
BMI (kg/m^2)	25.5 (6.7)	25.2 (5.9)	27.2 (8.0)	24.9 (5.9)	24.3 (6.5)	0.05
BMI-for-age z-score	0.84 (1.1)	0.86 (1.0)	1.1 (1.1)	0.78 (0.96)	0.62 (1.2)	0.09
≥85th percentile BMI-for-age (%)[d]	44.6 (3.0)[e]	48.7 (5.9)	49.4 (5.5)	41.3 (7.3)	36.6 (5.8)	0.35
≥95th percentile BMI-for-age (%)	25.4 (2.6)	28.4 (5.3)	32.9 (5.1)	19.6 (5.9)	16.9 (4.5)	0.092
Physical activity[f]						
Total physical activity	4.6 (3.6)	4.6 (3.4)	3.8 (3.1)	5.3 (3.1)	5.2 (4.3)	0.059
Moderate and vigorous physical activity	3.0 (2.8)	3.2 (3.1)	2.2 (2.3)	3.5 (2.6)	3.5 (3.2)	0.012
Total sedentary activity	31.1 (3.9)	31.3 (3.7)	31.7 (3.9)	30.7 (3.1)	30.6 (4.6)	0.30

[a] Ethnicity mutually exclusive (see Methods).

[b] P-values for differences across ethnic groups were from ANOVA for continuous variables (age, height, weight, BMI, and BMI-for-age) and Pearson χ^2 for categorical variables (% not US born, % above ≥85th percentile and above ≥95th percentile BMI-for-age).

[c] Mean (SD) all such values, except % not US born and % above ≥85th percentile and above ≥95th percentile BMI-for-age.

[d] BMI-for-age percentiles based on CDC's growth charts.

[e] SE given for overweight and obese sample percentages.

[f] The total number of 30-minute blocks self-reported for each activity type.

Table 2

Age-adjusted correlation coefficients[a] between DXA and BIA measures, by ethnicity.

	Total sample	White	Black	Hispanic	Asian
% fat	0.89	0.94	0.89	0.87	0.90
Fat mass	0.98	0.99	0.98	0.97	0.98
Fat-free mass	0.94	0.90	0.94	0.89	0.95
Fat mass index	0.97	0.98	0.98	0.97	0.98
Fat-free mass index	0.89	0.87	0.92	0.82	0.93

[a] All p-values for all correlation coefficients were <0.0001.

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Table 3

Mean[a] baseline levels of DXA and BIA measures and BIA bias, by ethnicity.

	Total	White	Black	Hispanics	Asians	p-value[b]
N	276	74	85	46	71	
DXA						
% body fat	36.9 (9.2)	36.5	39.1	37.0	34.8	0.037
Fat mass (kg)	25.0 (13.2)	25.4	29.3	23.8	20.4	<0.001
Fat-free mass (kg)	39.1 (7.6)	40.5	41.6	37.4	35.6	<0.001
Fat mass index (kg/m^2)[c]	9.9 (4.9)	9.7	11.1	9.6	8.8	0.025
Fat-free mass index (kg/m^2)[d]	15.6 (2.4)	15.4	16.0	15.3	15.4	0.30
BIA						
% body fat	30.6 (9.8)	30.5	34.3	30.9	26.3	<0.001
Fat mass (kg)	21.4 (13.2)	21.5	26.3	20.2	16.1	<0.001
Fat-free mass (kg)	43.0 (7.1)	44.6	45.0	41.2	40.1	<0.001
Fat mass index (kg/m^2)	8.4 (4.9)	8.2	10.0	8.2	6.9	0.001
Fat-free mass index (kg/m^2)	17.1 (2.3)	17.0	17.2	16.8	17.4	0.59
BIA-DXA[e]						
BIA-DXA % body fat	−6.3 (4.5)	−6.0	−4.8	−6.1	−8.6	<0.001
BIA-DXA fat mass	−3.7 (2.8)	−3.9	−2.9	−3.5	−4.3	0.012
BIA-DXA fat-free mass	3.9 (2.7)	4.1	3.3	3.8	4.5	0.051
BIA-DXA fat mass index	−1.5 (1.1)	−1.5	−1.1	−1.5	−1.9	<0.001
BIA-DXA fat-free mass index	1.6 (1.1)	1.6	1.3	1.6	2.0	0.002

[a]Ethnic-specific estimates are Least-square means from age-adjusted general linear regression models. Age was centered at the median (184 months). Means (SD) for the total sample are unadjusted.

[b]P-value of 4-level ethnicity term.

[c]Fat mass index = fat mass (kg)/height $(m)^2$.

[d]Fat-free mass index = fat free mass (kg)/height $(m)^2$.

[e]All BIA-DXA estimates statistically significantly (<0.05) different from 0 (no bias).

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Table 4

Estimated mean (SD) bias[a] in percent fat in the study sample based on published equations.

	Total population	White	Black	Hispanic	Asian
BIA-DXA, New Moves	−6.3 (4.5)	−5.9 (3.5)	−4.9 (5.0)	−6.4 (4.4)	−8.5 (4.2)
BIA (Tyrrell, 2001[b])-DXA	7.7 (3.8)	**7.1 (3.3)**[c]	8.1 (4.5)	8.0 (3.5)	7.6 (3.4)
BIA (McClanahan, 2009[d])-DXA	−1.7 (4.4)	−1.2 (3.5)	**−0.45 (4.9)**	−1.8 (4.3)	−3.6 (3.9)
BIA (Sluyter, 2010[e])-DXA	−7.5 (4.3)	**−8.8 (3.3)**	−6.1 (4.4)	−6.8 (3.9)	**−8.4 (4.6)**
BIA (Haroun, 2010[f])-DXA	−4.8 (5.6)	**−4.4 (4.6)**	**−4.9 (5.4)**	−0.75 (5.0)	**−7.7 (5.6)**

[a]Bias estimates were calculated directly from New Moves BIA and DXA data, and from New Moves BIA data corrected using four previously-published equations and New Moves DXA data.

[b]Study country: New Zealand; Study sample: 82 European, Maori, and Pacific Island children, ages 5–11; Equation: $FFM=0.31(ht^2/z)+0.17*ht+0.11*wt+0.942*sex$ (2=male; 1= female) −14.96. BIA: Leg-to-leg Tanita; Reference: DXA.

[c]Ethnicity group estimates are bolded if that ethnic group was included in the published study's sample.

[d]Study country: United States; Study sample: 183 African-American girls, ages 8–10; Equation: FFM=0.55+0.92*FFM, BIA. BIA: Leg-to-leg Tanita TBF-300; reference: DXA.

[e]Study country: New Zealand; Study sample: 216 Pacific Island, Asian, Maori, and European girls, ages 12–19; Equation: $FFM=0.531(ht^2/z)+0.182*ht + 0.096*wt + 1.562*ethnicity$(0=non-Pacific Island; 1=Pacific Island). BIA: 8-electrode Tanita BC-418; reference: DXA.

[f]Study country: England; Study sample: white (n=54), black (56), and Asian (91) adolescents girls, ages 11–15; Equation: $TBW=0.125+0.647*ht^2/z+2.187*black+1.465*Asian$; FFM=TBW/((79.797-(0.385*age))/100). BIA: Leg-to-leg Tanita TBF-300; reference: deuterium.