REVIEW

Validity of Body-Composition Methods across Racial and Ethnic Populations

Malia NM Blue,[1] Grant M Tinsley,[2] Eric D Ryan,[3] and Abbie E Smith-Ryan[3,4]

[1]Department of Exercise Science, High Point University, High Point, NC, USA; [2]Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, TX, USA; [3]Department of Exercise and Sport Science, The University of North Carolina, Chapel Hill, NC, USA; and [4]Department of Nutrition, The University of North Carolina, Chapel Hill, NC, USA

ABSTRACT

Multi-compartment body-composition models that divide the body into its multiple constituents are the criterion method for measuring body fat percentage, fat mass, and fat-free mass. However, 2- and 3-compartment body-composition devices such as air displacement plethysmography (ADP), DXA, and bioelectrical impedance devices [bioelectrical impedance analysis (BIA)] are more commonly used. Accurate measures depend on several assumptions, including constant hydration, body proportion, fat-free body density, and population characteristics. Investigations evaluating body composition in racial and ethnic minorities have observed differences in the aforementioned components between cohorts. Consequently, for racial/ethnic minority populations, estimates of body composition may not be valid. The purpose of this review was to comprehensively examine the validity of common body-composition devices in multi-ethnic samples (samples including >1 race/ethnicity) and in African-American, Hispanic, Asian, and Native American populations. Based on the literature, DXA produces valid results in multi-ethnic samples and ADP is valid for Hispanic and African American males when utilizing race-specific equations. However, for DXA and ADP, there is a need for validity investigations that include larger, more racially diverse samples, specifically including Hispanic/Latinx, Asian, Native American adults, and African-American females. Technology has advanced significantly since initial validity studies were conducted; therefore, conclusions are based on outdated models and software. For BIA, body-composition measures may be valid in a multi-ethnic sample, but the literature demonstrates disparate results between races/ethnicities. For BIA and ADP, the majority of studies have utilized DXA or hydrostatic weighing as the criterion to determine validity; additional studies utilizing a multi-compartment model criterion are essential to evaluate accuracy. Validity studies evaluating more recent technology in larger, more racially/ethnically diverse samples may improve our ability to select the appropriate method to accurately assess body composition in each racial/ethnic population. *Adv Nutr* 2021;12:1854–1862.

Keywords: body fat percentage, fat-free mass, validation, multi-ethnic, African American, Hispanic, Asian, Native American

Introduction

The high rates of obesity and cardiovascular and metabolic disease in minority populations (1–3) require a re-evaluation of our ability to assess and manage body composition effectively. According to the US Census Bureau, within the next 40 y, >50% of the US population will consist of individuals who identify as a racial/ethnic minority. However, many previous body-composition validation studies have not included minority populations or have failed to adequately report race/ethnicity of study participants. These omissions are important to consider as compartments of the body may vary depending on race and ethnicity (4), potentially leading to inaccurate assessments.

Body-composition assessments were established to accurately estimate the various components of body mass such as fat tissue, lean soft tissue, bone mineral content, and total body water (TBW). Multi-compartment models are currently considered the gold standard for molecular-level body-composition estimation and have the ability to account for multiple constituents, yielding more accurate estimates than simpler methods (5, 6). However, multi-compartment models require a minimum of 2 devices to measure additional compartments of the body and may not be the most feasible or practical technique. Therefore, single-device 2-compartment (2C) models [i.e., air displacement

Author disclosures: The authors report no conflicts of interest.

Supplemental Figure 1 and Supplemental Table 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/advances/.

Address correspondence to MNMB (e-mail: mblue@highpoint.edu).

Abbreviations used: ADP, air displacement plethysmography; BIA, bioelectrical impedance analysis; BIS, bioelectrical impedance spectroscopy; FFM, fat-free mass; FM, fat mass; HW, hydrostatic weighing; LOA, limits of agreement; MD, mean difference; SEE, standard error of the estimate; TBW, total body water; TE, total error; %fat, body fat percentage; 2C, 2-compartment; 3C, 3-compartment; 4C, 4-compartment.

© The Author(s) 2021. Published by Oxford University Press on behalf of the American Society for Nutrition. All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.

plethysmography (ADP), bioelectrical impedance analysis (BIA), bioelectrical impedance spectroscopy (BIS), and hydrostatic weighing (HW)] and 3-compartment (3C) models (i.e., DXA) are more commonly utilized to estimate fat mass (FM) and fat-free mass (FFM). Due to the measurement of fewer body compartments, several assumptions must be met for accurate estimates of body composition by these methods. Depending on the device, the validity of measures may be influenced by hydration, fat distribution, body proportions, and fat-free body density (6, 7). Investigations evaluating body composition in racial and ethnic minorities have observed differences in fat distribution (i.e., visceral vs. subcutaneous, intramuscular fat, trunk vs. limbs) (8–10), fat-free body density (4), and body proportions (4) between cohorts. Consequently, for racial/ethnic minority populations, estimates of body composition, especially by 2C models, may not be valid. The purpose of this review was to comprehensively examine investigations that evaluate validity of common body-composition devices in healthy, multi-ethnic samples (i.e., samples including >1 race/ethnicity), African-American/Black, Hispanic, Asian, and Native American populations. Results of this review may improve our understanding of what gaps exist in the current literature for body-composition assessment validity in racial/ethnic minority cohorts. Understanding the limitations of validity studies may also improve the ability of researchers and clinicians to select the most accurate method (**Supplemental Figure 1**) to assess body composition depending on the racial/ethnic composition of their study population, potentially leading to better classification of obesity-related disease risk.

Assessment of Validity

Validity is often evaluated by a combination of statistical analyses with the primary aim of evaluating the difference and relation between 2 measurements, with one typically serving as a criterion method. When evaluating group means, common statistical outcomes include mean difference (MD) ± SD, correlation coefficients (the relation between the 2 scores; e.g., Pearson's r or the concordance correlation coefficient), the coefficient of determination (r^2; the amount of variance shared by the 2 outcomes), total error (TE; the average deviation of individual scores from the line of identity, also known as root mean square error and pure error), and standard error of the estimate (SEE; the degree of deviation of the individual data points around the line of best fit). Evaluation of whether the intercept and slope of the line of best fit significantly deviate from the line of identity (intercept = 0, slope = 1) is also common. For individual-level differences, Bland-Altman analysis with the calculation of the 95% limits of agreement (LOA; representing the 95% likely reference range for the difference between method estimations) is often conducted. Simple linear regression analysis often accompanies the Bland-Altman analysis to determine if the level of agreement between methods varies based on the quantity of the variable being assessed (i.e., proportional bias). Therefore, for assessment of validity, this review will include all reported statistical procedures. For interpretation, we will follow the prediction error subjective rating scale outlined by Heyward and Wagner (11). Additionally, due to the limited data presenting validity of ADP and DXA in multi-ethnic samples, studies with small sample sizes (n = 2–8) of minority individuals were included.

Validity of DXA

DXA is widely considered as a valid method for measuring body composition. Although few recent studies have explored the validity of DXA within racial and ethnic minority populations, DXA devices are commonly used in large-scale, field-based studies (i.e., NHANES) as well as in clinical and laboratory settings. DXA devices measure FM, lean soft tissue, and bone mineral based on the attenuation of a dual-photon-energy low-dose X-ray beam. For valid measures, the DXA relies on proper patient positioning and accurate proprietary algorithms estimating soft tissue in body compartments containing bone (7). Bone content within a compartment is measured preferentially; therefore, the fat tissue and lean soft tissue overlying the bony structures are not measured directly (7). The estimation assumes uniformity of soft tissue distribution in the limb and trunk regions. Higher fat content within a region may be underestimated by DXA, influencing validity, specifically in the trunk region (12). A large previous study (n = 15,908) observed racial differences in fat distribution, with African Americans demonstrating greater fat mass in the limbs compared with Hispanic and White cohorts and Hispanic individuals having greater trunk fat mass (9). These variations may contribute to error of the DXA in racial and ethnic minorities. Validity results of investigations evaluating the DXA in racial and ethnic minority populations are presented in **Table 1**.

Validity within multi-ethnic samples

In a multi-ethnic sample of 23 individuals (White, Black, Puerto Rican), the DXA (Lunar DPX model) measures of FM demonstrated an excellent validity (MD of 1.51 ± 1.1 kg, SEE of 1.73 kg, and r^2 of 0.972) compared with the 6-compartment criterion method (5). A follow-up investigation in a similar population found no significant difference in percentage of fat (%fat) estimates (MD: 0.54% ± 2.4%; r = 0.983) between DXA (Lunar DPX v. 3.6) and the 5-compartment model (13). A study evaluating a fan beam DXA (QDR 4500A; Hologic) compared with a 4-compartment (4C) model in an older population reported an SEE of 1.6 kg for measures of FFM, and a strong correlation (r = 0.99) (14); however, it should be noted that only 10% of the sample was African American In a college-aged sample (36% Black) there were no significant differences between DXA %fat (QDR 1000W; Hologic) and the 4C model (MD: 0.4% ± 2.9%; r = 0.94; SEE = 2.8%) (14). In the multi-ethnic samples presented, DXA estimates demonstrated very good to excellent validity compared with multi-compartment models (6). However, the sample sizes were small and African Americans and Puerto Ricans are the only minorities represented, accounting for 10–47% of the

TABLE 1 Validity of DXA in multi-ethnic and minority samples of healthy adults[1]

Study	Criterion	Outcome	*n*	Race/ethnicity, *n*	Sex, % male	Age,[2] y	MD (±SD)[3]	TE[3]	SEE[3]	R^2	95% LOA
Wang et al. (5)	6C	FM	23	Multi (12 White, 3 Black, 8 Puerto Rican)	74	44.5 ± 16.3	1.51 (1.1)	1.31	1.73	0.972	−4.0 to 3.4
Wang et al. (13)	5C	%fat	27	Multi (14 White, 5 Black, 8 Puerto Rican)	78	43.8 ± 16.8	0.54 (2.4)	—	—	0.966	—
Prior et al. (15)	4C	%fat	172	Multi (62 Black, 110 White)	53	20.7 ± 2.6 (F); 21.2 ± 2.1 (M)	0.4 (2.9)	2.9	2.8	0.884	−5.3 to 6.1
Tylavsky et al. (14)	4C	FFM	58	Multi (6 Black, 52 White)	52	73.7 ± 2.2	2.8[4]	—	1.6	0.98	—
	4C	FFM	13	Multi (2 Black, 11 White)	38	72.5 ± 1.2	2.6[4,5]; −2.7[4,6]	—	—	—	—
Wagner and Heyward (16)	4C	%fat	30	Black	100	31.97 ± 7.71	−0.28	2.39	2.26	0.903	—
Collins et al. (17)	4C	%fat	39	Black	100	23.8 ± 5.7	−0.2	—	—	—	—
Deurenberg-Yap et al. (18)	4C	%fat	291	Asian (108 Chinese, 78 Malay, 107 Indian)	51	36.2 ± 12.0 (F)	2.1–2.5[4]	—	—	0.384[7]	—
						41.9 ± 12.9 (M)	3.2–4.2[4]			0.314[7]	—
Hicks et al. (19)	3C	%fat	147	Native American	0	34.5	0.3	3.27	3.28	0.785	±6.4

[1] FFM, fat-free mass; FM, fat mass; LOA, limits of agreement; MD, mean difference; SEE, standard error of the estimate; TE, total error; %fat, body fat percentage; 3C, 3-compartment model; 4C, 4-compartment model; 5C, 5-compartment model; 6C, 6-compartment model.
[2] Values are means ± SDs.
[3] Units for FM and FFM outcome variables are kg, units for %fat outcome variable is %.
[4] Significant mean difference between criterion and DXA ($P < 0.05$).
[5] Fan beam.
[6] Pencil beam.
[7] Partial correlation (corrected for age and ethnicity).

study sample population. Small studies (n = 10–30) should be evaluated with caution, particularly if conclusions indicate a method is valid for multi-ethnic samples and the study only included 2–5 individuals who are a racial/ethnic minority.

Validity by race/ethnicity

An investigation evaluating Native American females reported that DXA (Lunar DPX) measures of %fat demonstrated good to very good validity compared with a 3C density model (r^2 = 0.785, SEE = 3.28%, TE = 3.27%) (19). Conversely, 2 studies in black males (n = 30–39) found no significant differences between DXA (Lunar DPX) and 4C %fat estimates (MD = −0.28% to 0.20%) (16, 17). In a broad sample of 291 Asian males and females [BMI (kg/m^2) between 16 and 40], DXA (QDR 4500; Hologic) estimates of %fat were underestimated compared with the 4C (18). South Asian individuals have been shown to have greater visceral adipose tissue content (8), which may contribute to error in the trunk region estimate, decreasing %fat estimated by DXA in this population. To our knowledge, studies investigating the validity of DXA in Hispanic populations (20) and in larger multi-ethnic samples (21) have not been conducted in adults. Future investigations should evaluate the validity of DXA, particularly in adult Hispanic/Latinx populations, as well as in cohorts including both sexes for Black and Native American populations.

Validity of ADP

ADP consists of a dual-chamber, sealed compartment with an oscillating diaphragm that enables the device to quantify body volume utilizing Poisson's law (7). ADP assumes constant density of FM (0.9007 g/mL) and density of FFM (1.100 g/mL), which may be violated in racial/ethnic minority samples (22–24). Recently, it has been observed that Black individuals have greater FFM density (1.134 g/cm^3) and a higher ratio of bone mineral content to FFM compared with White individuals; Hispanic individuals' FFM characteristics may not vary significantly from those of White individuals (24). Differences in FFM characteristics may introduce error when estimating total body density and %fat from body volume using ADP, especially if utilizing general population equations [i.e., Siri (25) or Brožek et al. (26)] as opposed to race-specific body-density equations in African-American/Black cohorts. The body-density equations established by Schutte et al. (27) and Ortiz et al. (28) may improve estimates in Black males and females, respectively, by accounting for body-density differences. However, previous research has predominantly utilized general population body-density equations with ADP. Validity results of investigations evaluating ADP in racial and ethnic minority populations are presented in **Table 2**.

Validity within multi-ethnic samples

In a sample of Black and White males, race did not affect the accuracy of ADP (BOD POD; Life Measurement Instruments) %fat compared with a 4C estimate (White:

TABLE 2 Validity of ADP in multi-ethnic and minority samples of healthy adults[1]

Study	Criterion	Outcome	*n*	Race/ethnicity	Sex (%male)	Age,[2] y	MD (± SD)[3]	TE[3]	SEE[3]	R^2	95% LOA
Fields et al. (29)	4C	%fat	42	Multi (39 White, 3 Black)	0	32.8 ± 11.0	−1.8[4]	2.3	2.68	0.92	—
Lowry and Tomiyama (30)	DXA	%fat	64	Multi (57 White, 7 Asian)	78.3	55.0 ± 14.5	6.8 (4.4) (UW)[4]	—	—	—	−1.9 to 15.5
							2.4 (4.1) (NW)[4]				−5.6 to 10.3
							−1.7 (3.3) (OW)[4]				−8.1 to 4.7
Wingfield et al. (31)	DXA	%fat	24	Multi (17 White, 7 Black)	0	36.6 ± 12.0	1.6 (3.8)	—	—	0.44	−5.8 to 8.9
		FFM					0.98 (2.9)	—	—	0.81	−6.7 to 4.7
Alemán-Mateo et al. (32)	4C	FM	202	Mexican	49.5	69.0 ± 6.4	−0.93 (2.3)	—	2.3	0.93	−5.6 to 3.8
Alemán-Mateo et al. (33)	3C	%fat	37	Mexican	59.5	69.3 ± 6.5	−0.99 (1.4)	—	1.39	0.97	−1.5 to 0.5
Collins et al. (34)	4C	%fat	39	Black	100	23.8 ± 5.7	−3.6[4]	—	4.7	0.58	—
Wagner et al. (35)	DXA	%fat	30	Black	100	32.0 ± 7.7	−1.67[4]	—	2.84	0.86	—
Bi et al. (36)	DXA	%fat	445	Singaporean (91% Chinese)	41.3	37.5 ± 14.5	−3.9[4]	—	—	0.86	−2.3 to 10.2
Sasai et al. (37)	DXA	%fat	50	Japanese	100	47.8 ± 8.6	0.25 (2.9)	—	2.62	0.63	−5.52 to 6.02

[1]ADP, air displacement plethysmography; FFM, fat-free mass; FM, fat mass; LOA, limits of agreement; MD, mean difference; NW, normal weight; OW, overweight; SEE, standard error of the estimate; TE, total error; UW, underweight; %fat, body fat percentage; 3C, 3-compartment model; 4C, 4-compartment model.
[2]Values are means ± SDs.
[3]Units for FM and FFM outcome variables are kg, units for %fat outcome variable are %.
[4]Significant mean difference between criterion and ADP ($P < 0.05$).

SEE = 5.3%; Black: SEE = 4.7%) (17); however, ADP demonstrated poor validity and underestimated %fat for both races. In a study in females (7% Black), ADP %fat demonstrated good validity compared with a 4C model ($r^2 = 0.92$, SEE = 2.68%), although the very small number of Black females in the sample may limit the relevance of this finding to multi-ethnic populations (29). Several investigations have evaluated the validity of ADP using DXA as the criterion. However, there is not enough evidence to justify utilizing DXA as a criterion method in multi-ethnic samples; therefore, these evaluations must be interpreted with caution. In a sample of overweight/obese females (29% Black), ADP FFM and %fat estimates were not significantly different from DXA measures (FFM: MD = 0.98 ± 2.92 kg, $r = 0.90$; %fat: MD = 1.56% ± 3.75%) (31). An investigation of White and Asian/Asian Americans individuals ($n = 11.4\%$) determined that ADP %fat utilizing the Siri and Brožek et al. equations was significantly different compared with DXA; however, differences varied based on BMI category (underweight: MD = 7.3%; normal: MD = 2.4%; overweight: MD = −1.48%) (30). In multi-ethnic populations, the validity of ADP is variable depending on the level of body fat of the population, the body-density equation selected, and criterion method utilized. Future evaluation of ADP should investigate validity compared with a multi-compartment model criterion in larger samples with improved representation of racial/ethnic minorities across BMI categories.

Validity by race/ethnicity

In older Mexican males and females, ADP %fat was not significantly different than a 3C criterion [Siri et al. (25)] and had excellent validity ($r^2 = 0.97$, SEE = 1.39%); however, when evaluated by sex, males had significantly more variability in individual differences between methods (LOA = −4.4% to 2.5%) compared with females (LOA = −3.2% to 1.13%) (33). Similarly, in a larger sample ($n = 202$) of older Mexican adults, ADP FM estimates demonstrated very good validity compared with a 4C estimate ($r^2 = 0.93$, SEE = 2.3 kg) (32). These results are supported by the previous finding that no significant differences exist between White and Hispanic FFM characteristics. A study of 30 Black males determined that ADP had very good validity for %fat measures compared with DXA ($r^2 = 0.86$, SEE = 2.84%), with ADP slightly overestimating %fat (35). A large study of 445 Singaporean adults found ADP to significantly underestimate %fat compared with DXA (MD = 3.9%); however, adjusting for age, ethnicity, and BMI improved results (36). An investigation of 50 Japanese males demonstrated ADP and DXA tracked body-composition changes similarly following a diet or exercise intervention (Δ% DXA: −3.9% ± 2.9%; Δ% ADP: −3.9% ± 3.3%) (37). Very few studies have investigated race-specific validity of ADP in minority populations residing in the United States. In addition, to our knowledge, no studies have investigated the validity of ADP in Native Americans or Hispanic/Latinx individuals not of

Mexican descent. Future studies should aim to evaluate race-specific validity of ADP compared with a multi-compartment criterion including both male and female minority adults residing in the United States.

Validity of BIA

Single- and multi-frequency bioelectrical impedance devices quantify TBW by measuring the resistance of body tissue as an electrical current passes through the body (7). FFM can then be estimated by assuming a constant TBW to FFM ratio of 0.732. BIA estimations of TBW have previously been validated against isotope dilution as the criterion (38, 39). However, BIA devices, notably those that use a single frequency, are dependent on population characteristics such as age, race, sex, and training status, which may vary greatly when assessing multi-ethnic populations. Multi-frequency BIS devices do not depend on population characteristics by utilizing Cole plot analysis of impedance (reactance and resistance) at multiple frequencies; BIS assumes specific coefficients for resistivity of tissue, body proportion, and body density. Several investigations have evaluated the validity of bioelectrical impedance devices, primarily focused on the validity of regression equations (**Supplemental Table 1**) created in large populations [i.e., Segal et al. (40) and Lukaski et al. (41)] for use in special populations, including various races (42, 43), elderly (44), children (45, 46), overweight/obesity (47) and diseased states (48). Initial studies validated BIA %fat and FFM measures utilizing HW as the criterion method; however, more recent investigations have used DXA or a multi-compartment criterion. BIA devices are commonly used as a field-based technique within the fitness industry and athletics as well as in laboratory and clinical settings. Validity results of investigations evaluating bioelectrical impedance devices in racial and ethnic minority populations are presented in **Table 3**.

Validity within multi-ethnic samples

A large study in Native American (n = 247), Hispanic (n = 111), and White (n = 244) adults evaluated the validity of previously published BIA equations for estimates of FFM and reported excellent to poor validity depending on the equation (SEE of 2.22–5.21 kg, TE of 2.28–7.23 kg) compared with the HW criterion (49). However, HW is no longer considered a criterion for validation of methods; therefore, this study may not be appropriate for determination of validity in these samples. A recent investigation utilizing a 4C model criterion evaluated a multi-frequency BIA device (Seca Medical) regression equation in a multi-ethnic US population (n = 130; Hispanic, Asian, Black, and White) and reported TE between 1.9–2.2 kg for FFM (43). More recent investigations have aimed to establish and validate regression equations in multi-ethnic (Black, White, Hispanic, ≥2 races, Pacific Islander, Asian) samples of adolescents (45, 46) and adults (50), and found including race as a predictor variable improved accuracy. However, a consensus on the most appropriate regression equation to minimize mean and individual error has not been established. significantly limiting the application of BIA use in research and clinic.

Validity by race/ethnicity

Several studies have investigated the validity of BIA in Asian populations including Chinese, Indonesian, Malay, Indian, Singaporean Chinese, and Japanese participants. In 45 Indonesian adults, BIA (Seca 700) demonstrated large %fat MD (4.8–8.0%) when compared with the Siri (25) 3C model (51). In addition, in 298 Asian adults, BIA (Omron BF36) demonstrated fair validity (r = 0.87; SEE = 4.5%) compared with a 4C criterion (52). A study in 162 Indian males investigating the validity of %fat measured by leg-to-leg BIA (Beurer BF 60) and handheld BIA (Omron) found strong correlations (r = 0.741–0.817) with DXA measures and no significant difference between the leg-to-leg BIA estimates (MD = 0.72%) and DXA, but a significant difference for handheld estimates (MD = 4.44%) (53). As Indian cohorts may demonstrate greater fat in the trunk region (8), their distribution of fat supports utilizing tetrapolar devices as opposed to bipolar (leg-to-leg, handheld) for accuracy. A larger difference was observed in a study of 200 Indian adults between BIA (MC-180MA, Tanita Corporation) and DXA %fat values depending on the race-specific equation utilized (MD = 5.4–8.3%); both the White and Asian equations underestimated %fat (54). Studies that have created BIA regression equations in Chinese and Southeast Asian populations have determined excellent validity for lean body mass (MD = 2.8 kg, r^2 = 0.97, TE = 0.133) when validated against DXA (55). Similar to multi-ethnic populations, incorporating race-specific equations is important for valid estimates in Asian populations, but a consensus on the most accurate method may depend upon the country of origin and type of device used (i.e., tetrapolar, handheld vs. leg-to-leg).

Previous investigations assessing the validity in individuals of African descent have used a variety of criterion methods, thus limiting translation of these findings. Previous studies in Black males (n = 20–37) investigating BIA have demonstrated inconsistent validity compared with HW (56, 57). More recently, a study including 250 North African adults cross-validated (n = 125) a newly created regression equation and previously published equations compared with isotope dilution and reported variable error between equations for estimates of FFM (TE = 2.46–4.10 kg, LOA: −8.71–7.03 kg) (58). In a similar investigation, 5 BIA equation estimates of %fat were cross-validated with DXA estimates in a sample of 74 African-American females and found poor validity for all equations (SEE = 4.20–4.70%, r^2 = 0.39–0.52) (59). It has been reported in anthropologic studies that Black individuals have longer extremities and shorter trunk regions (4), which is particularly important for accuracy of bioelectrical impedance; regression equations utilize a standardized limb length to height ratio for measurements. Overall, bioelectrical impedance estimates in Black participants have demonstrated poor validity; however, further investigations assessing validity compared with a multi-compartment criterion are limited.

TABLE 3 Validity of bioelectrical impedance in multi-ethnic and minority samples of healthy adults[1]

Study	Criterion	Outcome	*n*	Race/ethnicity	Sex (%male)	Age,[2] y	MD (±SD)[3]	TE[3]	SEE[3]	R^2	95% LOA
Bioelectrical impedance analysis											
Bosy-Westphal et al. (43)	4C	FFM	130	Multi (31 Hispanic, 32 White, 31 Black, 36 Asian)	50	40.7	H: 0.4 (1.8)	1.9	—	—	−3.1 to 3.9
							W: 0.7 (2.1)	2.1			−3.4 to 4.8
							B: 1.5 (1.7)[4]	2.2			−1.8 to 4.8
							A: 0.7 (1.8)[4]	1.9			−2.8 to 4.2
Stolarczyk et al. (49)	HW	FFM	602	Multi (247 NA, 111 Hispanic, 244 White)	38.2	37.0 ± 13 (F)	0.14–3.17 (F)[4]	2.28–4.50	2.22–3.02	0.73–0.86	—
						33.5 ± 9.4 (M)	0.51–4.88 (M)[4]	3.62–7.23	3.59–5.21	0.76–0.89	—
Lopez et al. (59)	DXA	%fat	74	Black	0	47.6 ± 7.7	1.8	—	4.7	0.41	—
Wagner et al. (56)	HW	FFM	37	Black	100	30.8 ± 7.6	− 3.3	2.7–6.0	2.1–3.9	0.79–0.83	—
Stout et al. (57)	HW	%fat	20	Black	100	21.0 ± 3.0	7.0[4]	9.4	5.9	0.32	—
Aglago et al. (58)	D2O	FFM	125	North African	22.4	18–64	−3.0–0.04 (F)[4]	2.4–4.1	—	0.62–0.83[5]	—
							−2.5–0.97 (M)[4]	2.6–3.9	—	0.64–0.76[5]	—
Duerenberg et al. (52)	4C	%fat	298	Asian (140 Chinese, 72 Malay, 86 Indian)	49.5	36.2 ± 12.0 (F)	−0.7–1.5 (F)	—	4.5	0.76	—
						41.9 ± 12.9 (M)	0.7–2.0 (M)[4]				
Kupper et al. (51)	3C	%fat	41	Indonesian	43.9	21.2 ± 2.9 (F)	3.5 (2.4) (F)[4]	—	—	0.56	−1.2 to 8.2
						28.1 ± 6.6 (M)	2.8 (4.3) (M)[4]	—	—	—	−5.6 to 11.2
Vasudevan et al. (53)	DXA	%fat	155	Asian (Indian)	47	45.1 ± 9.0	4.5[4,6]	—	—	0.67[6]	−9.47 to 13.9
							0.7[7]			0.55[7]	−10.4 to 11.9
Nigam et al. (54)	DXA	%fat	200	Asian (Indian)	50	36.3 ± 7.5 (F)	− 8.3 (3.9)[8]	—	3.5–4.1[8]	0.59–0.62[8]	−20.1 to 9.4
						37.1 ± 7.7 (M)	− 5.4 (4.3)[9]	—	3.5–4.3[9]	0.54–0.63[9]	−20.6 to 11.4
Chen et al. (55)	DXA	FM	209	Chinese	51.2	27.6 ± 3.0	0.7	—	—	0.94	—
		LBM					2.8	0.133	—	0.97	—
Rising et al. (60)	HW	%fat	26	Native American	69.2	32 ± 10	0 (3)	—	3.22	0.85	—
							5 (7)	—	6.89	0.49	—
Stolarczyk et al. (42)	3C	FFM	47	Native American	0	34.5 ± 9.9	0.7	2.57	2.38	0.8	±4.9
Stolarczyk et al. (61)	4C	FFM	29	Hispanic	0	30.6 ± 5.5	−4.4–0.7	1.6–4.6	1.3–2.0	0.76–0.90	—
Macias et al. (62)	ADP	FFM	77	Mexican	47	34.0 ± 7.6	− 0.9 (2.8)	—	—	0.92	−6.6 to 4.8
Forrester et al. (48)	DXA	FFM	84	Hispanic	83.3	34.4 ± 7.2 (F)	− 3.4 (2.6)	—	—	0.79	−8.5 to 1.7
						36.9 ± 9.8 (M)	0.5 (3.4)			0.79	−6.1 to 7.2
Bioelectrical impedance spectroscopy											
Gibson et al. (63)	4C	%fat	146	Multi (50 White, 48 Black, 48 Hispanic)	50	33.1 ± 12.9 (F)	3.0[4]	5.5	4.8	0.77	—
						30.6 ± 13.6 (M)	0.2[4]	5.1	5.2	0.71	
Wi-Young et al. (64)	ADP	%fat	143	African American	44.8	20.0 ± 2.9 (F)	− 0.2	—	—	0.52	—
						21.7 ± 3.0 (M)	− 2.7			0.76	

[1] A, Asian; ADP, air displacement plethysmography; B, African American/Black; D2O, deuterium dilution; FFM, fat-free mass; FM, fat mass; H, Hispanic; HW, hydrostatic weighing; LBM, lean body mass; LOA, limits of agreement; MD, mean difference; NA, Native American; SEE, standard error of the estimate; TE, total error; W, Caucasian/White; %fat, body fat percentage; 3C, 3-compartment model; 4C, 4-compartment model.
[2] Values are means ± SDs.
[3] Units for FM, FFM, and LBM outcome variables are kg; units for %fat outcome variable are %.
[4] Significant mean difference between criterion and bioelectrical impedance measure ($P < 0.05$).
[5] Concordance correlation (ρ_c).
[6] Hand-held bioelectrical impedance analysis.
[7] Leg bioelectrical impedance analysis.
[8] Japanese-specific equation.
[9] Caucasian-specific equation.

In Hispanic populations, the validity of BIA estimates of body composition has not been thoroughly evaluated. A study investigating BIA estimates of FFM utilizing the Lukaski et al. (41) equation determined a significant difference in Hispanic females ($n = 14$, MD $= -3.4 \pm 2.6$ kg) but not males ($n = 70$, MD $= 0.54 \pm 3.4$ kg) compared with the DXA criterion; this could also be influenced by the small female sample size (48). In 29 Hispanic females, several BIA equations were evaluated and demonstrated very good to excellent validity for FFM (SEE = 1.4–2.0 kg; $r^2 = 0.76$–0.90) (42). Previous investigations did not use race-specific equations for Hispanic participants; therefore, a study in 155 adults from Mexico created ($n = 78$) and cross-validated ($n = 77$) a regression equation and found BIA FFM demonstrated good validity ($r^2 = 0.92$, MD $= 0.87 \pm 2.84$ kg) compared with ADP (62). Similar to other ethnicities, current literature in Hispanic individuals suggests BIA race-specific equations should be validated against a multi-compartment model.

Validity of BIA in Native American participants has not recently been evaluated. Rising et al. (60) evaluated the validity of BIA FFM estimates using the manufacturer (BIA-103; RJL Systems, Inc.) software (SEE = 6.89 kg) and a newly created equation in Native Americans (SEE = 3.22 kg), and determined that the race-specific equation improved validity from poor to acceptable compared with HW. A follow-up study in 151 Native American females determined race-specific and general BIA equations overestimated FFM (TE = 2.00–4.86 kg, SEE = 1.69–2.8 kg) compared with a multi-compartment criterion (61). As BIA equations are widely used in research and clinic, it is vital that future research assesses validity against a multi-compartment criterion and evaluates race-specific equations more consistently to allow for adoption of the most accurate race-specific equation within each racial/ethnic cohort.

Validity of BIS

Few studies have investigated the validity of multi-frequency BIS body-composition measures in minority populations. A study evaluating Black, White, and Hispanic adults ($n = 150$) reported that 2 tetrapolar BIS devices (Inbody 320 and Inbody 770) demonstrated significant mean differences in females (MD = 2.99%), but not males (MD = 0.36%), and poor validity compared with a 4C criterion (TE = 5.0–5.5%) (63). A study in African American college-aged adults ($n = 143$) showed BIS estimations were strongly correlated for FFM ($r = 0.911$–0.918) and %fat ($r = 0.717$–0.871) to ADP; however, additional validity statistics were not reported (64). Future studies should evaluate the validity of BIS measures in minority populations compared with the multi-compartment criterion; the usage of BIS would eliminate the need for population-specific regression equations, like those used in BIA. However, BIS body-composition estimates still rely on assumed FFM properties (e.g., TBW to FFM ratio of 0.73).

Summary and Conclusions

Although the minority population in the United States is increasing and is projected to become the majority by 2060 according to the US Census Bureau, racial/ethnic minorities are still underrepresented in body-composition investigations (65, 66). Due to the relation between body composition and cardiometabolic disease risk (67, 68), it is vital to thoroughly investigate this component of health in minority populations and determine if current assessment methods are valid. Differences in body proportion, fat-free body density, and hydration may have a larger effect on the validity of body-composition devices in minority populations than previously assumed. Based on the review of literature, DXA is a valid method in a multi-ethnic sample, if individuals are Caucasian/White and African American/Black. However, there is insufficient evidence to recommend use in Hispanic/Latinx and Asian adults, Native American males, or African-American/Black females. ADP is valid for Hispanic and African-American/Black males when utilizing race-specific equations; however, results are inconclusive in other racial/ethnic groups and sexes. For BIA, body-composition estimates may be valid in a multi-ethnic sample, but the literature demonstrates disparate results between races/ethnicities. BIA may provide valid results in Hispanic and Native American populations, as well as Asian populations utilizing race-specific equations. However, BIA is still not recommended for African-American/Black individuals based on current data. The lack of validation using a multi-compartment model criterion limits the certainty of conclusions, particularly regarding the validity of ADP and BIA.

Before continued widespread implementation of each body-composition device, there are several gaps in the existing body of research that should be addressed. For the DXA and ADP, there is a need for validity investigations that include larger and more racially diverse samples, specifically including Hispanic/Latinx and Asian adults, Native Americans, and African-American/Black females. The evidence to conclude that DXA is valid in multi-ethnic samples is lacking; the sample sizes of racial/ethnic minorities are likely too small to truly evaluate. For DXA, in particular, technology has advanced significantly since the initial validity studies were conducted, and therefore conclusions are based on outdated models and software. For ADP, future validity investigations should utilize a multi-compartment model as the criterion as opposed to DXA, especially for Asian individuals. For bioelectrical impedance, additional studies validating BIS against a multi-compartment model are essential to ensure accurate results. Studies in more recent and improved BIA and BIS technologies should be conducted in Native American, Hispanic/Latinx, and African-American/Black individuals. Additional validity investigations may improve our ability to select the appropriate method to accurately assess body composition in each racial/ethnic population. This is essential for understanding disease risk in society as a whole and improving exercise and diet recommendations for disease prevention and

management, as well as tracking changes from lifestyle interventions.

Acknowledgments

The authors' responsibilities were as follows—MNMB and AES-R: designed the research, wrote the manuscript, and had primary responsibility for final content; GMT and EDR: provided essential materials (i.e., assisted in acquisition of articles for review) and provided critical analysis; and all authors: read and approved the final manuscript.

References

1. Kurian AK, Cardarelli KM. Racial and ethnic differences in cardiovascular disease risk factors: a systematic review. Ethn Dis 2007;17:143–52.
2. Ong KL, Cheung BMY, Man YB, Lau CP, Lam KSL. Hypertension among United States adults 1999–2004. Hypertension 2007;49:69–75.
3. Sundquist J, Winkleby MA. Cardiovascular risk factors in Mexican American adults: a transcultural analysis of NHANES III, 1988–1994. 1998;1825:1988–94.
4. Wagner DR, Heyward VH. Measures of body composition in blacks and whites: a comparative review. Am J Clin Nutr 2000;1392–402.71
5. Wang ZM, Deurenberg P, Guo SS, Pietrobelli A, Wang J, Pierson RN, Heymsfield SB. Six-compartment body composition model: inter-method comparisons of total body fat measurement. Int J Obes 1998;22:329–37.
6. Heyward VH, Wagner DR. Use of regression analysis in body composition. 2nd ed.In: Applied body composition assessment. Champaign (IL): Human Kinetics Publishers, Inc.; 2004. p. 20.
7. Fosbøl MO, Zerahn B. Contemporary methods of body composition measurement. Clin Physiol Funct Imaging 2015;35:81–97.
8. Shah AD, Kandula NR, Lin F, Allison MA, Carr J, David H, Liu K, Kanaya AM. Less favorable body composition and adipokines in South Asians compared to other U.S. ethnic groups: results from the MASALA and MESA studies. Int J Obes 2016;40:639–45.
9. Hinton BJ, Fan B, Ng BK, Shepherd JA. Dual energy X-ray absorptiometry body composition reference values of limbs and trunk from NHANES 1999–2004 with additional visualization methods. PLoS One 2017;1–17.
10. Hill JO, Sidney S, Lewes CE, Tolan K, Scherzinger AL, Stamm ER. Racial differences in amounts of visceral adipose tissue in young adults: the CARDIA (Coronary artery Risk Development in young Adults) study. Am J Clin Nutr 1999;69:381–7.
11. Heyward VH, Wagner DR. Applied body composition assessment. 2nd ed. Champaign (IL): Human Kinetics Publishers, Inc.; 2004.
12. Milliken LA, Going SB, Lohman TG. Effects of variations in regional composition on soft tissue measurements by dual-energy X-ray absorptiometry. Int J Obes Relat Metab Disord 1996;20:677–82.
13. Wang Z, Heymsfield SB, Chen Z, Zhu S, Pierson RN. Estimation of percentage body fat by dual-energy X-ray absorptiometry: evaluation by in vivo human elemental composition. Phys Med Biol 2010;55:2619–35.
14. Tylavsky F, Lohman T, Blunt BA, Schoeller DA, Fuerst T, Cauley JA, Nevitt MC, Visser M, Harris TB. QDR 4500A DXA overestimates fat-free mass compared with criterion methods. J Appl Physiol 2003;94:959–65.
15. Prior BM, Cureton KJ, Modlesky CM, Evans EM, Sloniger, MA, Saunders M, Lewis RD, In vivo validation of whole body composition estimates from dual-energy X-ray absorptiometry. J Appl Physiol 1997;83:623–30.
16. Wagner DR, Heyward VH. Validity of two-component models for estimating body fat of black men. J Appl Physiol 2001;90:649–56.
17. Collins MA, Millard-Stafford ML, Evans EM, Snow TK, Cureton KJ, Rosskopf LB. Effect of race and musculoskeletal development on the accuracy of air plethysmography. Med Sci Sports Exercise 2004;36:1070–7.
18. Deurenberg-Yap M, Schmidt G, van Staveren WA, Hautvast J, Deurenberg P. Body fat measurement among Singaporean Chinese, Malays and Indians: a comparative study using a four-compartment model and different two-compartment models. Br J Nutr 2001;85:491.
19. Hicks VL, Heyward VH, Baumgartner RN, Flores AJ, Stolarczyk LM, Wotruba EA, Body composition of Native-American women estimated by dual-energy X-ray absorptiometry and hydrodensitometry. Basic Life Sci. 1993;60:89–92.
20. Ramirez E, Valencia ME, Moya Camarena SY, Aleman-Mateo H, Mendez RO. [Estimation of body fat by DXA and the four compartment model in Mexican youth.] Arch Latinoam Nutr Venezuela 2010;60: 240–6.
21. Wong WW, Hergenroeder AC, Stuff JE, Butte NF, Smith EO, Ellis KJ. Evaluating body fat in girls and female adolescents: advantages and disadvantages of DEXA. Am J Clin Nutr 2002;76:384–9.
22. Visser M, Gallaoher D, Deurenberg P, Wang J, Heymsfield SB. Density of fat-free body mass: Relationship with race, age, and level of body fatness. Am J Physiol Endocrinol Metab 1997;272:E781.
23. Deurenberg P, Yap M, Van Staveren W. Body mass index and percent body fat: a meta analysis among different ethnic groups. Int J Obes 1998;22:1164–71.
24. Tinsley GM, Smith-Ryan AE, Kim Y, Blue MNM, Nickerson BS, Stratton MT, Harty PS. Fat-free mass characteristics vary based on sex, race, and weight status in US adults. Nutr Res 2020;81:58–70.
25. Siri WE. Body composition from fluid spaces and density. Ha BJ, editor. Washington (DC): National Academy of Sciences; 1961.
26. Brožek J, Grande F, Anderson J, Keys A. Densitometric analysis of body composition: revision of some quantitative assumptions. Ann N Y Acad Sci 2006;110:113–40.
27. Schutte JE, Townsend EJ, Hugg J, Shoup RF, Malina RM, Blomqvist CG. Density of lean body mass is greater in blacks than in whites. J Appl Physiol 1984;56:1647–9.
28. Ortiz O, Russell M, Daley TL, Baumgartner RN, Waki M, Lichtman S, Wang J, Pierson Jr RN, Heymsfield SB. Differences in skeletal muscle and bone mineral mass between black and white females and their relevance to estimates of body composition. Am J Clin Nutr 1992;55: 8–13.
29. Fields DA, Wilson GD, Gladden LB, Hunter GR, Pascoe DD, Goran MI. Comparison of the BOD POD with the four-compartment model in adult females. Med Sci Sports Exerc 2001;33:1605–10.
30. Lowry DW, Tomiyama AJ. Air displacement plethysmography versus dual-energy X-ray absorptiometry in underweight, normal-weight, and overweight/obese individuals. PLoS One 2015;10:e0115086.
31. Wingfield HL, Smith-Ryan AE, Woessner MN, Melvin MN, Fultz SN, Graff RM. Body composition assessment in overweight women: validation of air displacement plethysmography. Clin Physiol Funct Imaging 2014;34:72–6.
32. Alemán-Mateo H, Huerta RH, Esparza-Romero J, Méndez RO, Urquidez R, Valencia ME. Body composition by the four-compartment model: validity of the BOD POD for assessing body fat in Mexican elderly. Eur J Clin Nutr 2007;61:830–6.
33. Alemán-Mateo H, Romero JE, Morales NM, Salazar G, Triana MH, Valencia ME. Body composition by three-compartment model and relative validity of some methods to assess percentage body fat in Mexican healthy elderly subjects. Gerontology 2004;50:366–72.
34. Collins MA, Millard-Stafford ML, Sparling PB, Snow TK, Rosskopf LB, Webb SA, Omer J. Evaluation of the BOD POD for assessing body fat in collegiate football players. Med Sci Sports Exerc 1999;31: 1350–6.
35. Wagner DR, Heyward VH, Gibson a L. Validation of air displacement plethysmography for assessing body composition. Med Sci Sports Exercise 2000;32:1339–44.
36. Bi X, Loo YT, Henry CJ. Body fat measurements in Singaporean adults using four methods. Nutrients 2018;10:303.
37. Sasai H, Nakata Y, Nemoto M, Ohkawara K, Ohkubo H, Matsuo T, Kim M-K, Katayama Y, Tanaka K. Air displacement plethysmography for estimating body composition changes with weight loss in middle-aged Japanese men. Obes Facts 2010;3:357–62.

38. Schoeller DA, van Santen E, Peterson D, Dietz W, Jaspan J, Klein P. Total body water measurement in humans with 18O and 2H labeled water. Am J Clin Nutr 1980;33:2686–93.
39. Armstrong LE. Assessing hydration status: the elusive gold standard. J Am Coll Nutr 2007;26:575S–84S.
40. Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB. Lean body mass estimation by bioelectrical impedance analysis: a four-site cross-validation study. Am J Clin Nutr 1988;47:7–14.
41. Lukaski HC, Bolonchuk WW, Hall CB, Siders WA. Validation of tetrapolar bioelectrical impedance method to assess human body composition. J Appl Physiol 1986;60:1327–32.
42. Stolarczyk LM, Heyward VH, Goodman JA, Grant DJ, Kessler KL, Kocina PS, Wilmerding V. Predictive accuracy of bioimpedance equations in estimating fat-free mas of Hispanic women. Med Sci Sport Exerc 1995;1450–6.
43. Bosy-Westphal A, Schautz B, Later W, Kehayias JJ, Gallagher D, Müller MJ. What makes a BIA equation unique? Validity of eight-electrode multifrequency BIA to estimate body composition in a healthy adult population. Eur J Clin Nutr 2013;67:S14–21.
44. Gába A, Kapuš O, Cuberek R, Botek M. Comparison of multi- and single-frequency bioelectrical impedance analysis with dual-energy X-ray absorptiometry for assessment of body composition in post-menopausal women: effects of body mass index and accelerometer-determined physical activity. J Hum Nutr Diet 2015;28:390–400.
45. Going S, Nichols J, Loftin M, Stewart D, Lohman T, Tuuri G, Ring K, Pickrel J, Blew R, Stevens J. Validation of bioelectrical impedance analysis (BIA) for estimation of body composition in Black, White and Hispanic adolescent girls. Int J Body Compos Res 2006;4:161–7.
46. Sluyter JD, Schaaf D, Scragg RKR, Plank LD. Prediction of fatness by standing 8-electrode bioimpedance: a multiethnic adolescent population. Obesity 2010;18:183–9.
47. Ramsey R, Isenring E, Daniels L. Comparing measures of fat-free mass in overweight older adults using three different bioelectrical impedance devices and three prediction equations. J Nutr Health Aging 2012;16:26–30.
48. Forrester JE, Sheehan HMB, Joffe TH. A validation study of body composition by bioelectrical impedance analysis in human immunodeficiency virus (HIV)-positive and HIV-negative Hispanic men and women. J Am Diet Assoc 2008;108:534–8.
49. Stolarczyk L, Heyward V, Loan MV, Hicks V, Wilson W, Reano L. The fatness-specific bioelectrical impedance analysis equations of Segal et al: are they generalizable and practical? Am J Clin Nutr 1997;66:8–17.
50. Stevens J, Truesdale K P, Cai J, Ou F-S, Reynolds KR, Heymsfield SB. Nationally representative equations that include resistance and reactance for the prediction of body fat in Americans. 2018;41:1669–75.
51. Kupper J, Bartz M, Schultink J, Lukito W, Deurenberg P. Measurements of body fat in Indonesian adults: comparison between a three-compartment model and widely used methods. Asia Pac J Clin Nutr 1998;7:49–54.
52. Deurenberg P, Deurenberg-Yap M. Validation of skinfold thickness and hand-held impedance measurements for estimation of body fat percentage among Singaporean Chinese, Malay and Indian subjects. Asia Pac J Clin Nutr 2002;11:1–7.
53. Vasudevan S, Mohan A, Mohan D, Farooq S, Raj D, Mohan V. Validation of body fat measurement by skinfolds and two bioelectric impedance methods with DEXA—the Chennai Urban Rural Epidemiology Study [CURES-3]. J Assoc Physicians India 2004;52: 877–81.
54. Nigam P, Misra A, Colles SL. Comparison of DEXA-derived body fat measurement to two race-specific bioelectrical impedance equations in healthy Indians. Diabetes Metab Syndr Clin Res Rev 2013;7: 72–7.
55. Chen W, Jiang H, Yang JX, Yang H, Liu JM, Zhen XY, Feng LJ, Yu JC. Body composition analysis by using bioelectrical impedance in a young healthy Chinese population: methodological considerations. Food Nutr Bull 2017;38:172–81.
56. Wagner DR, Heyward VH, Kocina PS, Stolarczyk LM, Wilson WL. Predictive accuracy of BIA equations for estimating fat-free mass of black men. Med Sci Sports Exerc 1997;29:969–74.
57. Stout JR, Eckerson JM, Housh TJ, Johnson GO. Validity of methods for estimating percent body fat in black males. J Strength Cond Res 1994;8:243–6.
58. Aglago KE, El Menchawy I, El Kari K, El Hamdouchi A, Barkat A, Benguedour R, El Haloui N, Mokhtar N, Aguenaou H. Development and validation of bioelectrical impedance analysis equations for predicting total body water and fat-free mass in North-African adults. Eur J Clin Nutr 2013;67:1081–6.
59. Lopez Y, O'Connor DP, Ledoux TA, Lee RE. Analysis of body composition methods in a community sample of African American women. Women Health 2011;51:709–23.
60. Rising R, Swinburn B, Larson K, Ravussin E. Body composition in Pima Indians: validation of bioelectrical resistance. Am J Clin Nutr 1991;53:594–8.
61. Stolarczyk LM, Heyward VH, Hicks VL, Baumgartner RN. Predictive accuracy of bioelectrical impedance in estimating body composition of Native American women. Am J Clin Nutr 1994;59:964–70.
62. Macias N, Alemán-Mateo H, Esparza-Romero J, Valencia ME. Body fat measurement by bioelectrical impedance and air displacement plethysmography: a cross-validation study to design bioelectrical impedance equations in Mexican adults. Nutr J 2007;6:1–7.
63. Gibson AL, Holmes JC, Desautels RL, Edmonds LB, Nuudi L. Ability of new octapolar bioimpedance spectroscopy analyzers to predict 4-component–model percentage body fat in Hispanic, black and white adults. Am J Clin Nutr 2008;332–8.87
64. Wi-Young S, Swearingin B, Brandon C, Rami L, Yunjung C, Dail TK, Melton D, Fuller M, Ha C. Body composition measurements determined by air displacement plethysmography and eight-polar bioelectrical impedance analysis are equivalent in African American college students. HealthMED 2012;6:6–9.
65. Sadar MR, Badri M, Prince CT, Seltzer J, Kowey PR. Underrepresentation of women, elderly patients, and racial minorities in the randomized trials used for cardiovascular guidelines. JAMA Intern Med 2014;174:1868–70.
66. Oh SS, Galanter J, Thakur N, Pino-Yanes M, Barcelo NE, White MJ, de Bruin DM, Greenblatt RM, Bibbins-Domingo K, Wu AHB, et al. Diversity in clinical and biomedical research: a promise yet to be fulfilled. PLoS Med 2015;1–9.
67. Müller MJ, Lagerpusch M, Enderle J, Schautz B, Heller M, Bosy-Westphal A. Beyond the body mass index: tracking body composition in the pathogenesis of obesity and the metabolic syndrome. Obes Rev 2012;13:6–13.
68. Barreira TV, Staiano AE, Harrington DM, Heymsfield SB, Smith SR, Bouchard C, Katzmarzyk PT. Anthropometric correlates of total body fat, abdominal adiposity, and cardiovascular disease risk factors in a biracial sample of men and women. Mayo Clin Proc 2012;87: 452–60.