



Original article

Prediction equations for body composition of children and adolescents aged 8–19 years in Uganda using deuterium dilution as the reference technique



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ARTICLE INFO

Article history:

Received 4 September 2018

Accepted 11 September 2018

Keywords:

Body composition
Bioelectric impedance analysis
Deuterium dilution method
Predictive equations
Children
Adolescents

SUMMARY

Background and aims: Body composition is important as a marker of both current and future health status. Bioelectrical impedance analysis (BIA) is a simple and accurate method for estimating body composition in field, clinical and research settings, if standard protocol procedures are followed. However, BIA requires population-specific equations since applicability of existing equations to diverse populations has been questioned. This study aimed to derive predictive equations for Total Body Water (TBW), Fat Free Mass (FFM) and Fat Mass (FM) determinations with BIA and anthropometric measurements in a population of children and adolescents aged 8–19 years in Uganda.

Methods: A cross-sectional study was conducted among 203 children and adolescents aged 8–19 years attending schools in Kampala district (also referred to as Kampala city since the city is conterminous with the district), Uganda through a two-stage cluster sample design. Deuterium dilution method (DDM) was used as the reference measure while BIA and anthropometric measures were used to create the new body composition prediction equations through multivariate regression.

Results: The new prediction equations explained 88%, 87% and 71% of the variance in TBW, FFM % and of FM respectively with no statistical shrinkage upon cross-validation. The linear regression models proposed in this study were well adjusted with respect to TBW, FFM and FM. Log of TBW obtained by DDM = $0.0129 \times \text{Impedance index} + 0.0055 \times \text{Age} + 0.0049 \times \text{Waist Circumference} + 0.1219\text{Ht}^2 + 2.0388$. Log of FFM obtained by DDM = $0.0197 \times \text{FFM obtained by BIA} - 0.0181 \text{ sex code} - 0.00055 \times \text{Impedance} + 3.1761$. Log of FM obtained by DDM = $0.0634 \times \text{FM obtained by BIA} - 0.1881 \text{ sex code} + 0.0252 \times \text{Weight} + 0.5273$.

Conclusion: The use of these equations for more accurate body composition assessment may facilitate identification of effective intervention strategies to prevent or combat overweight and obesity among children and adolescents. They may also assist in treatment of conditions where more accurate information on body composition measures is required.

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Abbreviations: BIA, Bioelectrical Impedance Analysis; TBW, Total Body Water; FFM, Fat Free Mass; FM, Fat Mass; %BF, Percentage Body Fat; DDM, Deuterium Dilution Method; DXA, Dual-energy X-ray Absorptiometry; WC, Waist Circumference; HC, Hip Circumference; WHR, Waist-to-Hip Ratio; WHtR, Waist-to-Height Ratio; VIF, Variance Inflation Factor; RMSE, Root Means-Squared Error.

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1. Introduction

Methods for evaluating and monitoring body composition in research and clinical practice should be accurate for the identification of possible health risks related to the excess or deficiency of different body components [1]. Accurate assessment of body composition, especially FM and FFM is a key aspect in prevention and management of many obesity-related non-communicable diseases [2] through correct identification of affected individuals and those at risk. In children and adolescents, accurate estimation of body composition is essential not only for the prevention but also

for the treatment of overweight [3]. Laboratory-based techniques of body-composition (TBW, FFM and FM) analysis, such as deuterium dilution, whole body potassium counting, hydrodensitometry, dual-energy X-ray absorptiometry (DXA), air plethysmography, and magnetic resonance imaging, are expensive, time consuming, need trained operators, and labor intensive therefore are not practical to use in population surveys or in routine clinical practice [2,4,5]. These techniques are also hardly feasible in most low- and middle-income countries like Uganda.

BMI is generally used to define overweight and obesity clinically [6] because it is easy to calculate, quick to measure and noninvasive [7]. However, BMI only provides indications of size and shape relative to normative data; it is not a measure of body composition as it does not differentiate levels of fat mass (FM) and fat-free mass (FFM) of the individual [8,9]. Thus BMI results are susceptible to misinterpretation. BIA on the other hand is considered a practical and useful technique for body composition assessment in clinics and field research settings as it may involve less inter-observer variation than do traditional anthropometric field measurements [10]. BIA is inexpensive, rapid, and noninvasive, and it has been proposed as an alternative to laboratory-based methods of measuring body composition [11].

BIA estimates TBW from which FFM can be computed by assuming a constant hydration of the FFM and, subsequently FM and percentage body fat (%BF) can be calculated [4]. BIA machines are usually equipped with a prediction equation that is built into the system that derives TBW and FFM using the impedance measurements, and the age, sex, weight and height values that are fed into the machine [12]. These BIA prediction equations for body composition tend to be population-specific [13]. While many studies have developed population specific equations to predict body composition from BIA [7,11] and anthropometry [14] measurements, no such study has been found specifically for the Ugandan population. Given that body composition and BIA results are influenced by age, gender and ethnicity [15], BIA equations should be developed specifically for the population of interest [16]. Reference techniques such as DDM can be a good option in developing regions that do not have access to the gold standard methodology like the four-compartment models [17] for validation of other techniques like BIA. Therefore, this study aimed to derive prediction equations for TBW, FFM and FM determinations with BIA and anthropometric measurements in a population of children and adolescents aged 8–19 years in Kampala Uganda.

2. Materials and methods

2.1. Subjects

In a cross-sectional study, 203 apparently healthy (based on self-proclamation) participants attending primary and secondary schools in Kampala city, Uganda were selected through a two-stage cluster sample design. The Ministry of Education and Sports provided an up to date list of all the primary and secondary schools in Kampala from which schools to participate in the study were randomly selected. Due to homogeneity between schools and between students in divisions of Kampala, schools were treated as clusters. Sampling of students from schools followed probability proportion to size procedure and a sample of 203 participants aged 8–19 years was randomly selected using random numbers.

Subjects who proclaimed themselves sick or were taking medications were excluded from the study. Participants' nutritional status was evaluated by anthropometric measurements: BMI, waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR) and their body composition was assessed by BIA and DDM. Immediately after the anthropometric and BIA

measurements were taken, saliva samples were collected from the subjects and D₂O doses were given to them. This permitted the assessments to be performed at the same time and under the same conditions, with a consequent constant state of hydration during all methods of body composition assessment used in the study.

2.2. Assessing height and weight

Height and weight were taken by trained researchers using standard equipment. Body weight was measured to the nearest 0.1 kg using a weighing scale, (Seca 899; Seca Weighing and Measuring Systems, Model No. 8691321004, SECA GmbH & Co. Germany made in China) with minimal clothing and no shoes. Height was measured to the nearest 0.1 cm using a height board (Shorr-board, height board, Weight and Measure LLC, Irwin J. Shorr, MPH, MPS. Olney, Maryland USA) without shoes.

2.3. Assessing waist and hip circumferences

WC was measured to the nearest 0.1 cm in standing position at the midpoint between the lowest rib and the iliac crest and at the end of normal expiration, using a measuring tape. Hip circumference (HC) was measured to the nearest 0.1 cm in standing position at the widest point of the hips. These measurements were made using a measuring tape (Lufkin Executive Diameter Steel Tape, 2 m Thinline Model W606PM, Apex Tool Group, LLC NC 27502, USA).

2.4. Computing BMI, waist-to- hip ratio and waist-to-height ratio

BMI (kg/m^2) was calculated as weight in kilogram divided by the square of height in meters. WHR was calculated as waist circumference divided by hip circumference both in the same SI units. WHtR was calculated as waist circumference divided by height both in the same SI units.

2.5. Assessing body composition by bioelectrical impedance analysis

Body composition by BIA was measured using a single frequency BIA (Tanita SC-331S Body Composition Analyzer; Tanita Inc., Arlington Heights, IL) instrument. The subject's age, gender, and height were entered into the machine, and a standard 0.5 kg was entered as an adjustment for clothing weight for all participants. The machine provided measures of FFM and FM using in-built manufacturers' equations and impedance. For this instrumentation, impedance is measured with the subject standing barefoot on the metal foot-plates of the machine for approximately 1 min. Impedance index was calculated as height in centimeters squared (cm^2) divided impedances in ohms (Ω).

2.6. Assessing body composition using deuterium dilution technique

A baseline saliva sample was collected from participants 2 h after their last meal. Each participant then received an oral dose of D₂O (0.5 g/kg body weight). The dose consumed was recorded to two decimal places of a gram. Two endpoint saliva samples were collected at 3 and 4 h after D₂O dose ingestion. Samples were stored in plastic saliva vials at -20°C until they were analyzed for D₂O using FTIR spectroscopy instrument (FTIR-8400S, Shimadzu Corporation, Japan) according to manufacturer's instructions. The instrument settings were: measurement mode: absorbance; apodization: square triangle; number of scans: 32; resolution: 2.0 and; range (cm^{-1}): minimum 2300 - maximum 2900.

A 'background' scan was performed using the unenriched drinking water that was used to make the calibration standard (zero standard) and the instrument was calibrated using a prepared D₂O standard (1000 mg/kg). TBW was calculated from the saliva sample by plateau method, based on the assumption that the plateau was reached at 3 or 4 h [18]. FFM was estimated from TBW as $FFM = TBW/\text{hydration factor}$. Age and gender specific hydration factors were used as these vary with age and gender [18]. FM and % BF were calculated from FFM.

2.7. Ethics approval and consent to participate

The purpose and objectives of the study were carefully explained to each participant and their parents. Informed consent to the study was obtained from participants' parent/guardian to affirm their willingness to allow their children to take part in the study or not. The participants signed assent forms, accepting to participate in the study. Ethical clearance to engage human subjects was obtained from Makerere University School of Biomedical Sciences Higher Degrees, Research and Ethics Committee and Uganda National Council for Science and Technology under reference numbers: SBS 291 and HS 1950 respectively.

2.8. Data preparation

All data were entered into an MS Excel database that was created for the study. The data were rechecked for any missing data and entry errors. A spreadsheet containing all data (from anthropometric, BIA and DDM measurements) was imported into STATA. Normality of variables was inspected visually using normal histogram plots. Box plots were used to inspect for data outliers where 8 outliers were removed. Variables that did not exhibit normality were transformed by log transformation.

2.9. Data analysis

Participants' descriptive characteristics were presented as means and confidence intervals. The body composition parameters that were obtained through DDM as the reference technique were used to develop regression equations for children and adolescent populations in Uganda. To generate the prediction equations for estimating body composition in this population, multivariate regression analysis was used. Data were randomly divided into 2; working and validation samples. The means of the two samples were subjected to paired t-test to assess if they statistically differed. Relationships between DDM measured TBW, FFM and FM and predictive variables (from BIA and anthropometry) were tested by bivariate analysis. Variables with $p > 0.05$ were not considered for the multivariate analysis. For linear regression models, values obtained by DDM for FFM (kg), TBW (L) and FM (kg) as the dependent variables while values obtained by BIA (FFM, FM, body fat (%), impedance, impedance index) and anthropometry (weight, height, BMI, WC, HC, WHR and WHtR) as well as age and sex as the independent variables were considered. Multicollinearity was evaluated using variance inflation factor (VIF). A VIF of 10 was considered appropriate. Best prediction equations were those that had a the largest R^2 with minimum root means-squared error (RMSE) [2]. An R^2 value of not less than 0.328 has been regarded as sufficient for a good regression model [19] while 0.25 is regarded as the arbitrary cut-off value for RMSE, values larger than which are considered too large [20]. Heteroskedasticity of the regression variables was tested using the Breusch–Pagan test [21].

Validity of the predictive model was determined by comparing means of the actual measures (assessed by DDM) to the predicted measures using paired t-test analysis. To show the relationship

between actual and predicted measures, Pearson product-moment correlation was considered. The Bland Altman plots examined the agreement between FFM, FM and TBW estimated by DDM and those from the prediction equations. Mean differences and limits of agreement were calculated according to Bland Altman procedures. The analyses were done using STATA version 12 software and the level of significance was set at $P < 0.05$.

3. Results

3.1. Descriptive statistics

The study sample constituted of 195 children and adolescents aged 8–19 years with an average age of 13.4 years (Table 1). Means for anthropometric variables of weight, height, BMI, WC, HC, WHtR and WHR were 44.61 kg, 1.51 m, 19.07 kg/m², 65.87 cm, 82.48 cm, 0.44 and 0.80, respectively. The means and confidence intervals of FFM (kg), FM (kg) and %BF were: 36.56 (35.30–37.82), 8.05 (7.23–8.87) and 16.95 (15.74–18.17) by respectively by DDM and 37.46 (36.13–38.79), 7.15 (6.50–7.81) and 15.31 (14.34–16.27) respectively by BIA respectively (Table 1).

Randomized procedures produced a working and validation sample. The randomly split dataset consisted of 103 subjects in the working sample and 92 subjects in the validation sample. The anthropometry, BIA and DDM measurements that were taken from subjects in both the working and validation samples were not significantly statistically different at a significance level of $P > 0.05$ (Table 2).

On assessing the relationship between TBW, FFM and FM obtained through DDM and age, sex, anthropometric measurements and BIA variables through bivariate regression analysis, all measurements were significantly associated with DDM measurements except % body fat obtained by BIA that was not significantly associated with TBW and FM measurements and WHtR that was not significantly associated with TBW (Table 3).

The models selected for TBW, FFM and FM on basis of maximum R^2 with minimum RMSE and low VIF values (Table 4) had: R^2 values of 0.88, 0.87 and 0.71 respectively; with RMSE values 0.09, 0.09 and 0.36 respectively and mean VIF values of 5.32, 2.74 and 2.03 respectively, indicating absence of multicollinearity. For the developed predictive equations, the chi square values were small: $\chi^2(1) = 0.41, 0.99$ and 0.17 and not significant: $\text{Prob} > \chi^2 = 0.52, 0.32$ and 0.68 for TBW, FFM and FM respectively.

Table 1
Study participants' characteristics.

Characteristic	Mean	95% Confidence interval
N	195	
Age (years)	13.44	12.98–13.90
Weight (kg)	44.61	42.92–46.31
Height (m)	1.51	1.50–1.53
BMI (kg/m ²)	19.07	18.64–19.50
WC (cm)	65.87	65.02–66.71
HC (cm)	82.48	80.97–83.99
WHtR	0.44	0.43–0.44
WHR	0.80	0.80–0.81
BIA Impedance (Ω)	573.79	561.67–585.92
BIA Impedance index (cm ² / Ω)	41.77	40.14–43.41
DDM TBW (L)	26.76	25.84–27.68
DDM TBW (%)	60.79	59.90–61.68
DDM FFM (kg)	36.56	35.30–37.82
BIA FFM (kg)	37.46	36.13–38.79
DDM FM (kg)	8.05	7.23–8.87
BIA FM (kg)	7.15	6.50–7.81
DDM (% BF)	16.95	15.74–18.17
BIA (% BF)	15.31	14.34–16.27

Table 2
Descriptive statistics of the working and validation samples.

Characteristic	Working sample (n = 103)		Validation sample (n = 92)		P-value
	Mean	CI	Mean	CI	
Age (years)	13.45	12.80–14.09	13.43	12.78–14.09	0.98
Weight (kg)	44.14	41.79–46.50	45.14	42.65–47.63	0.57
Height (m)	1.52	1.49–1.54	1.51	1.49–1.53	0.64
BMI (kg/m ²)	18.74	18.18–19.30	19.43	18.76–20.09	0.12
WC (cm)	65.42	64.27–66.57	66.37	65.12–67.62	0.27
HC (cm)	81.97	80.00–83.94	83.06	80.71–85.41	0.48
WHtR	0.43	0.43–0.44	0.44	0.43–0.45	0.06
WHR	0.80	0.79–0.81	0.81	0.79–0.82	0.80
BIA Impedance (Ω)	578.84	561.46–596.23	568.14	551.09–585.19	0.39
BIA Impedance index (cm ² /Ω)	41.77	39.39–44.16	41.78	39.54–44.02	0.99
DDM TBW (L)	26.81	25.49–28.12	26.71	25.41–28.02	0.92
DDM TBW (%)	61.48	60.25–62.71	60.02	58.72–61.32	0.12
DDM FFM (kg)	36.62	34.82–38.42	36.49	34.71–38.27	0.92
BIA FFM (kg)	37.43	35.48–39.37	37.50	35.67–39.33	0.96
DDM FM (kg)	7.52	6.41–8.63	8.65	7.42–9.87	0.18
BIA FM (kg)	6.72	5.87–7.56	7.64	6.61–8.66	0.17
DDM Fat (%)	16.01	14.33–17.69	18.01	16.23–19.78	0.12
BIA Fat (%)	14.73	13.43–16.02	15.95	14.50–17.41	0.21

Table 3
Relative importance of BIA and anthropometric variables in predicting TBW, FFM and FM of the children and adolescents.

Variables	TBW		FFM		FM	
	R ²	P-value	R ²	P-value	R ²	P-value
Age (years)	0.58	0.0000	0.26	0.0000	0.15	0.0000
Height (m)	0.77	0.0000	0.24	0.0000	0.07	0.0001
Weight (kg)	0.79	0.0000	0.44	0.0000	0.35	0.0000
Sex	0.03	0.0244	0.03	0.0244	0.16	0.0000
BMI (kg/m ²)	0.45	0.0000	0.45	0.0000	0.57	0.0000
WC (cm)	0.55	0.0000	0.41	0.0000	0.31	0.0000
HC (cm)	0.57	0.0000	0.33	0.0000	0.46	0.0000
WHR	0.16	0.0000	0.05	0.0000	0.21	0.0000
WHtR	0.00	0.5863	0.07	0.0002	0.17	0.0000
BIA %BF	0.01	0.1766	0.02	0.0825	0.49	0.0000
Impedance (Ω)	0.70	0.0000	0.61	0.0000	0.13	0.0000
Impedance index (cm ² /Ω)	0.90	0.0000	0.90	0.0000	0.20	0.0000
BIA FM (kg)	0.16	0.0000	0.12	0.0000	0.62	0.0000
BIA FFM (kg)	0.87	0.0000	0.46	0.0000	0.14	0.0000

Table 4
BIA and anthropometric prediction equations for TBW, FFM and FM.

Equation	R ²	RMSE	Mean VIF	Chi ²	Prob > Chi ²
$\log TBW = 0.0129 \times \text{Impedance index} + 0.0055 \times \text{Age} + 0.0049WC + 0.1219Ht^2 + 2.0388$	0.88	0.09	5.32	0.41	0.52
$\log FFM = 0.0197 \times \text{BIAFFM} - 0.0181 \text{ sex code} - 0.00055 \times \text{Impedance} + 3.1761$	0.87	0.09	2.74	0.99	0.32
$\log FM = 0.0634 \times \text{BIAFM} - 0.1881 \text{ sex code} + 0.0252 \times \text{Weight} + 0.5273$	0.71	0.36	2.03	0.17	0.68

Sex code: male = 0; female = 1, Ht² = height in meters squared, BIAFFM = FFM obtained by BIA, BIAFM = FM obtained by BIA.

The means of the TBW, FFM and FM measured by DDM compared to those estimated by the developed prediction equations using paired t-test analysis, were not significantly different at P-value = 0.69, = 0.83 and = 0.17 respectively, indicating that the models were valid (Table 5).

Table 5
Mean estimates of TBW, FFM and FM with DDM and the new equations.

Variable	Mean estimates (confidence intervals)		P-value
	DDM	Prediction equation	
TBW (L)	26.71 (25.41–28.02)	26.62 (25.43–27.81)	0.68
FFM (kg)	36.49 (34.71–38.27)	36.57 (34.97–38.17)	0.83
FM (kg)	8.65 (7.42–9.87)	8.11 (6.80–9.42)	0.17

The means of the FFM and FM measured by BIA compared to those estimated by the developed prediction equations using paired t-test analysis, were significantly different at P-value = 0.03 and = 0.01 respectively, indicating that the BIA ad the predictive equations may ot be used interchangeably (Table 6).

Table 6
Mean estimates of FFM and FM with BIA and the new equations.

Variable	Mean estimates (confidence intervals)		P-value
	BIA	Prediction equation	
FFM (kg)	37.46 (36.13–38.79)	36.57 (34.97–38.17)	0.03
FM (kg)	7.15 (6.50–7.81)	8.11 (6.80–9.42)	0.01

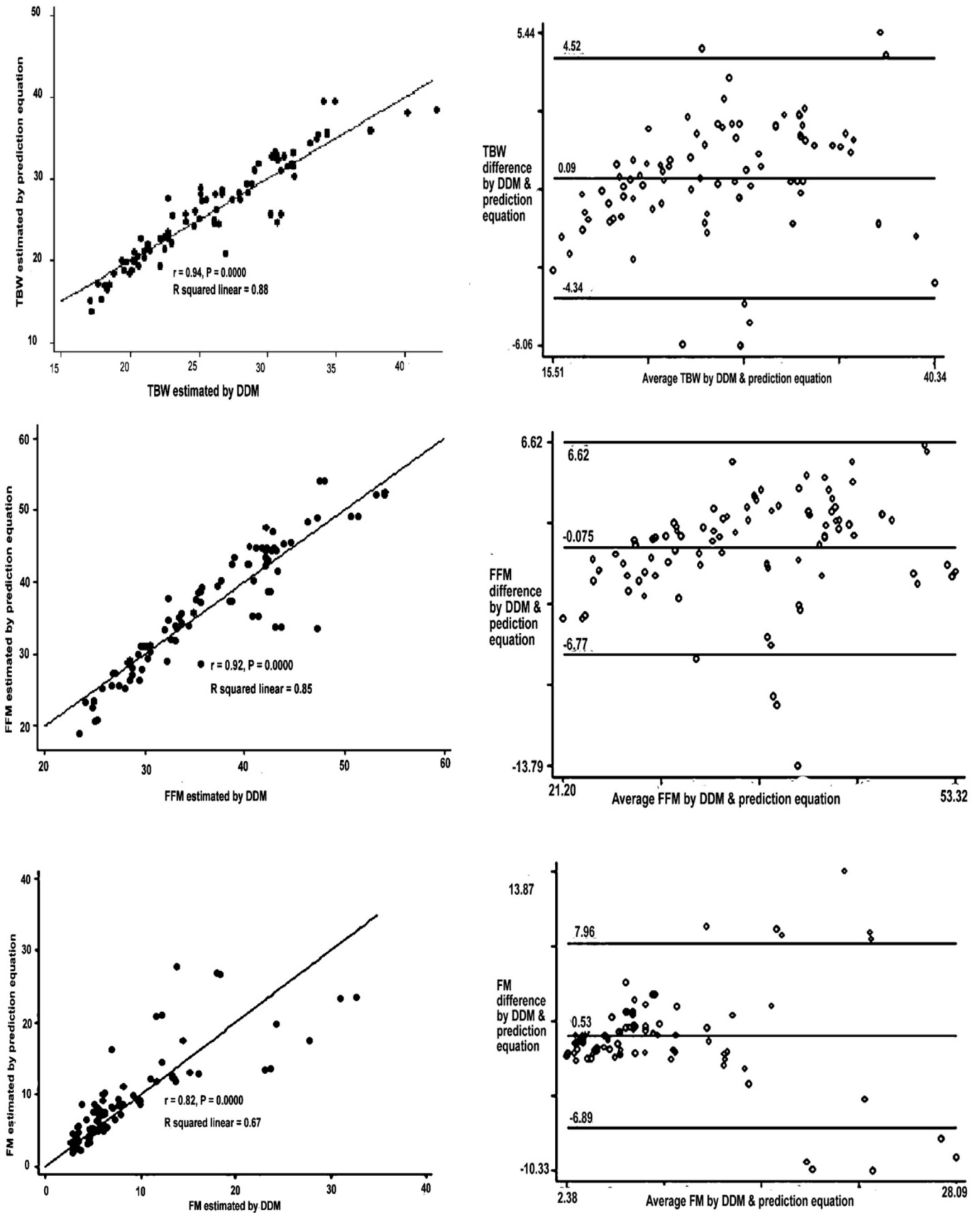


Fig. 1. Regression (left) and Bland–Altman (right) plots for TBW (upper), FFM (middle) and FM (lower) determined by DDM and the developed prediction equations.

The correlations between the DDM estimated TBW, FFM and FM and those by the prediction equations were high and positive among the study subjects at $r = 0.94, 0.92,$ and 0.82 respectively (Fig. 1, left side plots) demonstrating a strong association between the DDM and prediction equation estimated measures. Bland and Altman analysis examined the bias in the discrepancy between each predictive equation and DDM for measuring TBW, FFM and FM. No significant bias was found in either prediction equations (Fig. 1, right side plots). The mean bias of the TBW, FFM and FM prediction equations were 0.093 L (95% CI -0.37 to 0.55), -0.075 kg (95% CI -0.77 to 0.62) and 0.53 kg (95% CI -0.23 to 1.31) respectively. The Bland–Altman plots showed random nature of spread with no detectable proportional bias for measured and predicted TBW, FFM and FM values among the study subjects. Bland Altman analysis also revealed narrow limits of agreement between measured and predicted values of TBW, FFM and FM.

4. Discussion

Predictive equations with BIA and anthropometric measurements have been in use for body composition assessment however, these are often representative of the population from which they were generated. Three equations based on bioelectrical impedance analysis were found invalid for evaluation of total body water and fat-free mass assessment in infants and young children in India; concluding that population-specific equations are desirable for a more precise measures [22]. Therefore, it is important that Ugandan population specific predictive equations are used in assessment of their body composition in Uganda as predictive equation are population specific [23]. When predictive equations have been used to predict body composition in populations different from those that generated data for their development, the results have been inconsistent [16]. The primary purpose of this investigation was to provide new and valid body composition prediction equations to more accurately measure the body composition of children and adolescents aged 8–19 years in Uganda. With the increasing rates of childhood and adolescent overweight and obesity in Uganda [24], accurate assessment of body composition among children and adolescents, especially FM and FFM is a key aspect in prevention and management of many obesity-related non-communicable diseases [2] through correct identification of affected individuals and those at risk. Availability of easily performed measures of body composition so that the effectiveness of intervention strategies can be more accurately compared is critical in fighting overweight and obesity. Identifying the most effective intervention strategies may ultimately provide great assistance in the fight against the rising number of overweight and obese children and adolescents.

In the present study, predictive equations for TBW, FFM and FM from BIA and anthropometric measures have been generated and validated using data from a sample of 195 healthy children and adolescents aged 8–19 years that attended primary and secondary schools in Uganda. The values for TBW, FFM and FM obtained from DDM (the reference method) were used. These are the first set of body composition predictive equations for populations in Uganda. We recommend using these simple prediction equations since the means of the DDM and prediction equations estimated values of TBW, FFM and FM were not significantly different. Generally, BIA and anthropometry have practical advantages compared to DDM. Other than being a safe, noninvasive, and reliable approach for estimating human body composition, BIA offers other advantages of a relatively inexpensive cost, rapid measurements, portability, little operator skill and subject involvement required [7]. Anthropometric measures are cheap, quick and simple to perform [25].

In our bivariate analysis, impedance index was the best predictor for TBW and FFM. These findings are similar to those by

Kushner and other who reported that the single best predictor of total body water (TBW) was $\text{height}^2/\text{resistance}$ (ht^2/R), which explained 99% of the variation in TBW [26]. The TBW prediction equation was with R^2 of 0.88 and RMSE of 0.09 L, the FFM prediction equation was with R^2 of 0.87 and RMSE of 0.09 kg and the FM prediction equation with R^2 of 0.71 and RMSE of 0.36 kg compare favorably with results reported by Liu and others [8]. The study by Liu and others had comparable participant characteristics and using DDM as the reference technique. In the study by Liu and others, the TBW equation was with R^2 of 0.88 and RMSE of 1.3 kg and the FFM equation was with R^2 of 0.88 and RMSE of 1.7 kg. The small and insignificant chi square values for the developed prediction equations indicate absence of heteroskedasticity implying the variability of the variables is equal across the range of values of those that predict.

Since the means of the actual TBW, FFM and FM (measured by DDM) compared to those predicted by the developed equations using paired t-test analysis were found not to be significantly different (Table 5), the predictive equations are therefore valid and could substitute the labor intensive, time consuming and sophisticated DDM [5]. The generally narrow limits of agreement and minimal biases reveal that DDM and developed prediction equations agree and can be used interchangeably for TBW, FFM or FM among children and young adolescents in Uganda. Therefore, the new prediction equations can provide a useful alternative in epidemiological studies.

5. Conclusions

The current study presented three novel prediction equations for estimating body composition of Ugandan populations 8–19 years. The new equations were precise, accurate and had a low RMSE, low mean VIF values and high R^2 values. These equations can therefore be applied in the field and in clinical settings, depending on the availability of BIA and anthropometric instruments. However, the TBW and FFM prediction equations showed the greatest precision and accuracy. They are therefore the best suited for research and clinical applications. BIA is a non-invasive, portable, and relatively inexpensive method. Anthropometric measures are simple and easy to perform. The new prediction equations provide a valuable tool that can be used to identify childhood and adolescent overweight and obesity by providing alternative valid measures of body composition and to allow a more accessible means of comparing the effectiveness of intervention strategies. The use and application of these body composition prediction equations may also be extended beyond their primary intent to other uses including determining medication dosing and assisting in rehabilitative patient care planning and progress monitoring.

Competing interests

The authors declare that they have no competing interest.

Funding

The International Atomic Energy Agency (IAEA) offered the study support under project number UGA6017.

Authors' contributions

DN, CTN and JHM conceived and designed the study. CTN did the literature search. CTN did data collection. BO did the statistical analysis. DN, CTN and JHM drafted and revised the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors are grateful to the children and adolescents who participated in this study, their parents/guardians, schools' administration and teachers and the entire research team.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clnesp.2018.09.004>.

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