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RESEARCH ARTICLE

Segmental bioelectrical impedance in the assessment of body composition of Sri Lankan children

V.P. Wickramasinghe[1*], S.P. Lamabadusuriya[1], G.J. Cleghorn[2] and P.S.W. Davies[2]

[1] *Department of Paediatrics, Faculty of Medicine, University of Colombo, P.O. Box 271, 25, Kynsey Road, Colombo 8.*

[2] *Children's Nutrition Research Centre, Department of Paediatrics and Child Health, University of Queensland, Brisbane, Australia.*

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Abstract: Over the years bioelectrical impedance assay (BIA) has gained popularity in the assessment of body composition. However, equations for the prediction of whole body composition use whole body BIA. This study attempts to evaluate the usefulness of segmental BIA in the assessment of whole body composition.

A cross sectional descriptive study was conducted at the Professorial Paediatric Unit of Lady Ridgeway Hospital, Colombo, involving 259 (M/F:144/115) 5 to 15 year old healthy children. The height, weight, total and segmental BIA were measured and impedance indices and specific resistivity for the whole body and segments were calculated. Segmental BIA indices showed a significant association with whole body composition measures assessed by total body water (TBW) using the isotope dilution method (D_2O). Impedance index was better related to TBW and fat free mass (FFM), while specific resistivity was better related to the fat mass of the body. Regression equations with different combinations of variables showed high predictability of whole body composition. Results of this study showed that segmental BIA can be used as an alternative approach to predict the whole body composition in Sri Lankan children.

Keywords: Fat free mass, fat mass, impedance index, segmental BIA, specific resistivity, Sri Lankan children.

INTRODUCTION

Traditionally, a change occurring in disease and the response to treatment was assessed by anthropometry. Height, weight, skin fold thickness and circumferences have been the prime tools used for this. However, advances in knowledge regarding the changes that occur in body and the availability of advanced assessment techniques, have enabled physicians to look deeper into specific changes that occur due to disease. Although the available sophisticated techniques give accurate results, most need expensive equipment and trained personnel with the cooperation from the patients. These were significant drawbacks in the assessment of human body composition. Considration of the bioelectrical impedance assessment (BIA) was an answer to this problem to an extent, where, the technique was simple and non-threatening to children, cost effective and portable. The BIA equipment is simple to handle and requires minimum training and could be operated at bed side. The technique has gained popularity and now has more extensive usage, especially in adults.

Although research on electrical conductivity of biological tissues dates back to the beginning of the twentieth century, only in 1962 Thomosset demonstrated its usefulness in clinical practice (Baumgartner, 1996). Hoffer *et al.* (1969) validated its use on a group of adults and showed its ability to estimate total body water with greater accuracy. Since then many researchers have validated the use of whole body BIA in assessing whole body composition across many populations (Wickramasinghe *et al.*, 2008a), but work related to the applicability of segmental BIA in assessing whole body composition is scarce in both children (Fuller *et al.*, 2002a) and adults (Fuller & Elia, 1989; Organ *et al.*, 1994).

BIA assesses body composition by measuring the impedance of body to a flow of electrical current. Such indirect techniques need validation before using on a population other than that had been used to develop the equation (Wickramasinghe *et al.*, 2008a). Differences in

[*] Corresponding author (pujithaw@yahoo.com)

size, shape, degree of hydration and ethnic origin may have contributed to such differences in body composition. Therefore, equations to suit different populations have been validated (Deurenberg *et al.*, 2002).

Scientists have been attempting to validate different segmental assessment techniques, for the assessment of whole body composition. Skin fold thickness had been used to estimate whole body fat mass (FM). However, due to its selected number of sites, and changes in body contour and fat distribution in different individuals, the use of skin fold thickness has been unsuccessful. Therefore, segmental bioelectrical impedance analysis has been studied for its applicability in whole body composition assessment. Although segmentally measured, the electric conductivity is affected by the composition of the whole body and theoretically should provide a better assessment of whole body composition. The segmental assessment techniques that could assess regional as well as whole body composition are useful in clinical practice. It is primarily useful for patients having difficulties in measuring their body composition due to difficulties in reaching the necessary equipment (i.e. due to ventilation, bedbound state, etc.) or cannot access the required sites of the body due to trauma, plaster casts, burns, skin diseases etc. Therefore, a segmental assessment technique that would enable the assessment of regional body composition, as well as whole body composition would be invaluable. The segmental BIA has been considered to assess the composition of body segments, including muscle and adipose tissue massess of whole limbs, limb segments and defined sections of body and results are comparable to measures obtained using the dual-energy x-ray absorptiometry (DEXA) (Fuller *et al.*, 2002b). Previous studies in adults and children have shown that certain segmental assessments correlate well with total body composition (Baumgartner *et al.*, 1989; Fuller & Elia, 1989; Organ *et al*., 1994). To improve the predictability, more variables are needed to be tested. However, this would lose the purpose of the use of segmental assessment methods, as they are mainly planned for individuals who find it difficult to be subjected to many measurements (Organ *et al*., 1994). This study was aimed at determining the potential of segmental BIA measures in predicting whole body composition in 5 to 15 year old Sri Lankan children.

METHODS

Subjects

Five to 15 year old healthy Sri Lankan children were recruited from schools in Colombo. The schools were selected to represent children from different socioeconomic backgrounds and stratified according to the age, to get a fair representation of age and sex. Cluster sampling technique was adopted, where one class from each grade, 1 to 10, were selected randomly and all the students were invited to participate in this study. Students to a class were allocated randomly and therefore it was considered not necessary to select them randomly. Children who were ill during the preceding 2 weeks or those who were undergoing any special physical training, that could have altered their body composition were excluded.

The study was conducted at the clinical laboratory of the Professorial Paediatric Unit of Lady Ridgeway Hospital for Children, Colombo, from September 2004 to April 2005. Both parents and children were informed about the procedure. Informed written consent from the parents and assent from the children were obtained. The Ethical Review Committees of University of Colombo and Lady Ridgeway Hospital for Children approved the study.

Measurements

The height was measured using a stadiometer (Surgical and Medical Products, Australia) to the last completed 0.1 cm and the weight was measured with minimal lightweight clothing to the closest 100 g, with an electronic weighing scale (Soehnle®, Soehnle-Waagen GmbH & Co, Germany) using the standard techniques. BMI was calculated by weight/height^2 (kgm^{-2}). The total body water (TBW) was measured by isotope dilution method using deuterium in the form of water (D_2O) as described by Wickramasinghe *et al.* (2008b). The fat free mass (FFM) was calculated from TBW using age and gender specific water content of FFM (Lohman, 1989). The absolute FM was calculated by subtracting FFM from weight, based on the two-compartment body composition model. Percentage FM is when FM was expressed as a fraction of body weight. FMI and FFMI were calculated by FM/height^2 (kgm^{-2}) and FFM/height^2 (kgm^{-2}), respectively.

The circumferences of the following sites were measured using a non-elastic flexible tape to the closest 0.1 cm and utmost privacy was maintained when taking the measurements. Measurements were taken with no clothes intervening in the area being measured and details of the technique of measurement are as follows.

Mid upper arm circumference was measured at the mid point between the lateral projection of acromial process of scapula and the inferior border of the olecranon process with the arm flexed at 90^0. Measurement was taken with the arm relaxed and the elbow extended and hanging just away from the side of the trunk, with palms facing the lateral aspect of thigh.

Mid forearm circumference was measured at the mid point between the styloid process of the ulna and the inferior border of the olecranon process, while the subject was standing with arms relaxed and palms facing the lateral aspect of thigh.

Mid thigh circumference was measured at midway between the mid point of the inguinal crease and the proximal border of the patella (located when knee is extended) and measured perpendicular to the long axis of the thigh. Measurement was taken while the subject was standing with the feet kept about 20 cm apart and weight distributed equally on both feet.

Mid calf circumference was measured at mid point between the lateral maleolus and the tibio-fibular joint. Measurements were taken while the subject was seated and the measured foot kept on the ground and the knee flexed to 90^0.

Waist circumference was measured with the subject standing erect with abdomen relaxed, arms at the sides of the body and feet together. The measurement was taken in the horizontal plane, at the level of midpoint between the costal margin and the iliac crest in the mid axillary line. It was considered to be the same as mid circumference of the trunk segment.

Hip circumference was measured with the subject standing erect with the arms by the sides of the body and feet together. The circumference was measured at the maximum extension of the buttocks, seen from the lateral side (Callaway, e*t al*., 1988). Cross sectional area was calculated using circumference data (circumference^2/4л).

BIA measurement

BIA was measured with single frequency (50 kHz) four surface-electrode technique, with an electric current of 800 µA, using Bodystat instrument® (Bodystat Ltd, Isle of Man, British Isles). The subject lay supine on a bed with a non-conductive surface. Hands were kept in the prone position and slightly abducted so that they were not touching the trunk. Legs were abducted to place a minimum of 20 cm between the two medial malleoli, to avoid the thighs touching each other (Baumgartner, 1996). For the whole body impedance measurement, the surface electrodes for the source current (discharging electrodes) were placed at the third metacarpo-phalangeal joint in the left hand and third metatarso-phalangeal joint of the left foot and the sensing electrodes were kept at midway between the styloid processors and malleoli of the left wrist and left ankle respectively. A minimum distance of 5 cm was maintained between the source and sensing electrodes, to avoid any interference. If the natural distance was less than 5 cm, the sensing electrode was moved proximally till the desired distance was achieved (Baumgartner, 1996). Conduction gel coated disposable surface electrodes (5 cm^2, Kendall Q-Trace 5400®, Ludlow Company Ltd., USA) were used and connected to the BIA machine *via* crocodile clips.

The segmental impedance was measured, while keeping the source electrodes as placed for whole body impedance measurement (vide supra). The sensing electrodes for forearm segment was placed at wrist midway, between the styloid processors and at the elbow directly above the olecranon of the ipsilateral arm; for upper arm segment, electrodes were kept between the left elbow (vide supra) and left acromion. Impedance of upper limb was measured by keeping electrodes at wrist and acromium. Impedance of leg was measured by placing the sensing electrodes at mid way between the maleolie of ankle joint and at the knee, laterally over the femoral-tibial joint. Impedance of thigh was measured by placing sensing electrodes at the femoral-tibial joint and at anterior superior iliac spine. Impedance of lower limb was measured by placing the sensing electrodes at ankle joint and anterior superior iliac spine. Impedance of trunk is measured by placing electrodes at left acromion and left anterior superior iliac spine. The distance between the mid points of the measured segmental BIA electrodes were taken as the segmental length and was measured to the closest 0.1 cm.

Impedance index ($cm^2\Omega^{-1}$) was calculated by height^2 (cm) /impedance (Ω) and specific resistivity (Ωcm) as resistance (Ω) × cross sectional area (cm^2)/ segment length (cm). In each instance, the cross sectional area was taken at the mid point of the segment. For the calculation of resistivity of the upper limb the average of the cross sectional area of upper arm and fore arm was used and for the lower limb, the average of the cross sectional area of thigh and leg was used. For calculation of resistivity of the whole body, the cross sectional area of body was estimated by averaging the cross-sectional areas of the upper limb, trunk, and lower limb (Organ *et al.*, 1994).

Statistics

Pearson product moment correlation was calculated

Table 1: Characteristics of the study population

Variable characteristics	Female 115	Male 144
Age (yrs)	9.9 ± 2.7	9.6 ± 2.7
Weight (kg)	34.9 ± 12.9	31.2 ± 12.5*
Height (cm)	138.2 ± 15.3	134.4 ± 15.5
BMI (kgm^{-2})	17.7 ± 3.9	16.6 ± 3.6*
TBW (L)	16.6 ± 6.1	16.9 ± 5.5
FM (kg)	13.2 ± 6.9	8.9 ± 6.5*
FFM (kg)	21.7 ± 8.1	22.3 ± 7.4
FMI (kgm^{-2})	6.7 ± 2.8	4.6 ± 2.6*
FFMI (kgm^{-2})	11.0 ± 2.5	12.0 ± 1.9*
% FM	37.1 ± 10.6	26.2 ± 10.3*
WC (cm)	64.4 ± 11.0	60.4 ± 11.3*
HC(cm)	74.1 ± 11.9	68.6 ± 11.3*
WHR	0.87 ± 0.07	0.88 ± 0.05

*p < 0.05

between anthropometric measures and measures of body composition to evaluate the association among anthropometry, impedance indices and body composition. Significance was considered at $p < 0.05$. Stepwise multiple regression was performed to identify the best predictors of whole body composition. The adjusted coefficient of determination (R^2) was used to assess the magnitude of contribution of the variable to the regression. Root mean squared error (RMSE) was used to assess the prediction error. Data were analyzed using NCSS computer package for windows (NCSS/PASS 2000, Dawson Edition).

RESULTS

A total of 259 children (144 boys and 115 girls) were recruited. Table 1 shows the characteristics of the study population. Boys were slightly younger. Except for TBW and FFM, all other parameters were significantly different

Table 2: Mean length, circumference at mid point and cross sectional area at mid point of each segment of body of each gender

Segment of body variables	Female (115) Segment length (cm)	Circumferences (cm)	Cross sectional area (cm^2)	Male (144) Segment length (cm)	Circumferences (cm)	Cross sectional area (cm^2)
Forearm	21.4 ± 3.1	16.5 ± 2.3	36.9 ± 15.3	20.6 ± 3.2*	15.8 ± 2.5*	32.8 ± 14.3*
Upper arm	24.8 ± 3.4	21.2 ± 4.1	22.1 ± 6.3	23.3 ± 3.5*	19.9 ± 4.2*	20.3 ± 6.6*
Upper limb	46.3 ± 6.3	-	29.5 ± 10.5	43.7 ± 6.8*	-	26.6 ± 10.3*
Trunk	35.5 ± 4.7	64.4 ± 11.0	339.7 ± 117	34.7 ± 4.2	60.4 ± 11.3*	300.0 ± 118*
Thigh	41.1 ± 5.8	41.4 ± 8.4	141.8 ± 60.2	38.9 ± 5.3*	38.3 ± 8.0*	121.4 ± 53.8*
Leg	33.9 ± 4.9	25.1 ± 4.1	51.6 ± 18.5	32,6 ± 5.2*	23.7 ± 4.9*	46.7 ± 23.7
Lower limb	75.0 ± 10.4	-	96.7 ± 35.9	71.5 ± 10.2*	-	84.0 ± 37.5*

*p < 0.05 when compared between gender within each parameter

Table 3: Details of impedance measurement of whole body and segments of each gender

Whole body and segment variables	Female (115) Impedance (Ω)	Impedance as a fraction of total body impedance (%)	Impedance index (cm^{2}Ω^{-1})	Resistivity (Ω cm)	Male (144) Impedance (Ω)	Impedance as a fraction of total body impedance (%)	Impedance index (cm^{2}Ω^{-1})	Resistivity (Ω cm)
Whole body	801 ± 103	-	24.8 ± 7.5	869.0 ± 185	767 ± 95.5*	-	24.7 ± 8.2	748.5 ± 178*
Arm	233 ± 31	29.1 ± 1.9	2.8 ± 0.9	332.5 ± 86.2	220 ± 29*	28.7 ± 1.6*	2.6 ± 0.97	295.8 ± 83.4*
Fore arm	180 ± 30	22.4 ± 1.6	2.7 ± 1.2	180.2 ± 25.3	169 ± 26*	22.0 ± 1.4*	2.7 ± 1.1	161.7 ± 31.4*
Upper limb	402 ± 57	51.1 ± 2.0	5.6 ± 2.0	245.6 ± 43.0	379 ± 52*	49.4 ± 1.7*	5.4 ± 2.2	221.0 ± 50.1*
Trunk	76 ± 11	9.5 ± 1.1	17.7 ± 6.6	707 ± 193.0	75 ± 9	9.8 ± 0.7*	16.8 ± 6.0	622.0 ± 157.5*
Thigh	110 ± 17	13.7 ± 0.9	16.5 ± 6.4	361.3 ± 96.0	106 ± 15*	13.8 ± 0.9	15.1 ± 5.7	314.2 ± 80.0*
Leg	251 ± 32	31.4 ± 2.1	4.8 ± 1.6	368.9 ± 9.0	240 ± 29*	31.3 ± 1.8	4.7 ± 1.8	328.1 ± 98.4*
Lower Limb	348 ± 46	43.4 ± 2.1	17.1 ± 6.01	430.6 ± 97.1	335 ± 40*	43.8 ± 1.7	16.0 ± 5.8	375.9 ± 95.1*

*p < 0.05 when compared between gender within each parameter in the two groups. Table 2 shows the mean segmental length, circumference and cross sectional area for each segment of the body of each gender and the values were significantly different in the two groups.

Table 4: Relationship between estimated whole body composition assessments and anthropometric or impedance in Sri Lankan children

Variables	TBW		FFM		FFMI		FM		FMI		%FM	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Height	0.88	0.80	0.89	0.81	0.41	0.40	0.64	0.58	0.41	0.27	0.29	0.05*
Weight	0.91	0.88	0.91	0.88	0.63	0.66	0.88	0.83	0.74	0.63	0.55	0.20**
BMI	0.71	0.69	0.70	0.69	0.71	0.70	0.86	0.81	0.86	0.77	0.66	0.30
Age	0.77	0.70	0.79	0.71	0.31	0.32	0.53	0.45	0.31	0.14*	0.21	-0.004*
Impedance												
Whole body	-0.70	-0.72	-0.69	-0.72	-0.65	-0.71	-0.56	-0.50	-0.51	-0.41	-0.35	-0.000*
Upper arm	-0.54	-0.50	-0.54	-0.49	-0.59	-0.57	-0.41	-0.36	-0.40	-0.34	-0.26	-0.01*
Fore arm	-0.74	-0.73	-0.54	-0.73	-0.67	-0.66	-0.61	-0.61	-0.55	-0.49	-0.38	-0.11*
Upper limb	-0.67	-0.65	-0.67	-0.65	-0.67	-0.66	-0.54	-0.51	-0.51	-0.43	-0.34	-0.05*
Trunk	-0.67	-0.68	-0.67	-0.69	-0.62	-0.51	-0.42	-0.44	-0.32	-0.24**	-0.14*	0.03*
Thigh	-0.73	-0.78	-0.72	-0.78	-0.58	-0.68	-0.58	-0.52	-0.49	-0.33	-0.33	0.02*
Leg	-0.51	-0.57	-0.51	-0.56	-0.51	-0.62	-0.42	-0.32	-0.41	-0.28**	-0.27	0.06*
Lower limb	-0.63	-0.69	-0.62	-0.68	-0.57	-0.68	-0.51	-0.42	-0.49	-0.33	-0.34	0.05*

All correlations had a significant level of $p < 0.01$ unless stated otherwise. * $p>0.05$, ** $0.01 < p < 0.05$

Table 5: Relationship between estimated whole body composition assessments and segmental impedance index or segment specific resistivity index in Sri Lankan children

Variables	TBW		FFM		FFMI		FM		FMI		%FM	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Impedance index												
Whole body	0.92	0.90	0.93	0.91	0.56	0.61	0.67	0.64	0.49	0.36	0.33	0.02*
Upper arm	0.88	0.88	0.89	0.85	0.54	0.57	0.64	0.60	0.46	0.34	0.32	0.03*
Fore arm	0.90	0.84	0.91	0.85	0.56	0.58	0.69	0.70	0.51	0.45	0.35	0.10*
Upper limb	0.91	0.84	0.92	0.88	0.55	0.61	0.68	0.67	0.49	0.36	0.33	0.06*
Trunk	0.89	0.77	0.90	0.78	0.65	0.51	0.68	0.56	0.53	0.31	0.34	0.03*
Thigh	0.88	0.87	0.88	0.87	0.47	0.56	0.64	0.61	0.43	0.32	0.30	-0.00*
Leg	0.86	0.85	0.87	0.86	0.50	0.56	0.67	0.57	0.49	0.31	0.34	-0.00
Lower limb	0.90	0.87	0.91	0.88	0.50	0.58	0.68	0.59	0.48	0.31	0.33	-0.01
Segment specific resistivity index												
Whole body	0.49	0.35	0.49	0.34	0.76	0.43	0.52	0.64	0.80	0.72	0.65	0.41
Upper arm	0.51	0.49	0.51	0.49	0.80	0.50	0.50	0.61	0.83	0.61	0.70	0.30
Fore arm	-0.02*	-0.11*	-0.02*	-0.12*	0.27	0.15*	0.14*	0.05*	0.37	0.23**	0.34	0.14*
Upper limb	0.32	0.39	0.32	0.38	0.66	0.48	0.41	0.54	0.73	0.62	0.63	0.32
Trunk	0.47	0.18*	0.47	0.17*	0.79	0.34	0.50	0.48	0.82	0.62	0.70	0.36
Thigh	0.55	0.24	0.55	0.23**	0.72	0.29	0.57	0.47	0.74	0.52	0.60	0.29
Leg	0.54	0.22**	0.54	0.22**	0.45	0.25	0.50	0.42	0.42	0.46	0.32	0.27
Lower limb	0.62	0.36	0.61	0.35	0.69	0.37	0.59	0.62	0.68	0.62	0.54	0.34

All correlations had a significant level of $p < 0.01$ unless stated otherwise. * $p > 0.05$, ** $0.01 < p < 0.05$

Segmental bioelectrical impedance analysis

Table 3 shows the mean impedance for each segment, segmental impedance as a fraction of the measured total impedance, impedance index and specific resistivity. All indices were significantly higher in females, except for impedance index. The sum of segmental impedance was greater than the total impedance measured. The sum of five segments (fore arm, upper arm, trunk, thigh and leg) was higher by 6.1 % and 5.6 % in girls and boys, respectively. When 3 segments were considered (upper limb, trunk and lower limb), the over - estimation was by 4 % and 3 % in girls and boys, respectively. This change in percentage would have been due to the change in electrodes with the measurement of each segment.

Cross sectional area for the calculation of resistivity of whole body, upper limb and lower limb were based on the mean of the relevant segments (vide supra). The impedance index in both groups were quite similar, however girls had a significantly higher specific resistivity. This is to be expected as the fat content is quite high in females.

Table 4 shows the relationship between estimates of whole body composition assessments and anthropometry or impedance measures. Except for percentage FM in girls, anthropometric measures had a significant association with body composition measures. Anthropometric parameters had a stronger association with TBW, FFM and FM than with FFMI, FMI and % FM. Although statistically significant, the relationships between age and body composition measures were weak. Similarly, the measured impedance had a significant association with body composition parameters, except for % FM. However, the strength of the associations was weaker than those of anthropometry. Once the impedance was adjusted to length (impedance index) (Table 5), the associations improved and high associations were seen with all body composition measures except % FM. It was equally seen in both gender groups. Some of the associations seen with impedance index were stronger than anthropometry.

Although segmental resistivity showed a statistically significant association (Table 5) with body composition measures, they were weaker than impedance index. The segment specific resistivity index of forearm, did not show statistically significant associations with most of the body composition measures in both gender groups.

In order to identify which anthropometric measure of body could substitute height and weight, correlation between height and weight with different body parameters were assessed (Table 6). The segmental lengths showed strong correlation with height, and the cross sectional areas showed stronger correlation with weight. Both correlations are to be expected, as the segmental lengths contribute to linear growth, and the increase in cross section is due to increase in soft tissues (muscles and adipose), which contributes to increase of weight.

Impedance indices in isolation and in combination with other anthropometric measures were regressed on TBW and FFM determined by hydrometry (D_2O) (Table 7). Predictability in males was always slightly higher than in females. Combinations of impedance indices improved the predictability. The best prediction of TBW, in both genders, was given when impedance indices of upper limb, lower limb and trunk were used in combination with weight (boys R^2 = 0.88, RMSE 1.9 L and girls R^2 = 0.82, RMSE 2.6 L). The same combination gave the highest predictability for FFM, but RMSE was much higher. This could be due to the proportionate inflation of the FFM when derived from TBW, and whether FFM is directly derived from the BIA prediction equation or derived through TBW estimations, the ultimate error could be similar. Although adding weight improved the predictability, the purpose of introducing segmental assessment of body composition is to overcome any difficulty in measuring the whole body weight or other measure involving the whole body. Therefore, addition of weight would lose the purpose of use of segmental parameters in the assessment of whole body composition. Further, weight was replaced by other

Table 6: Correlation coefficients for weight, height, segmental lengths and segmental cross sectional area of each gender

	Male (144)		Female (115)	
	Height	Weight	Height	Weight
Length				
$L_{upper\ limb}$	0.93	0.79	0.96	0.84
L_{Trunk}	0.82	0.83	0.82	0.74
$L_{Lower\ limb}$	0.98	0.83	0.98	0.78
$L_{Forearm}$	0.92	0.80	0.93	0.84
$L_{Upper\ arm}$	0.94	0.81	0.94	0.80
L_{Thigh}	0.95	0.77	0.95	0.80
L_{Leg}	0.96	0.85	0.94	0.78
Area				
$A_{Upper\ arm}$	0.68	0.94	0.58	0.82
$A_{Forearm}$	0.73	0.93	0.64	0.91
A_{Trunk}	0.64	0.92	0.54	0.88
A_{Thigh}	0.72	0.93	0.61	0.83
A_{Leg}	0.62	0.78	0.54	0.88

anthropometric parameters, which showed best relation to weight (Table 6). Substitution of weight with the length of upper limb gave very similar values for prediction of TBW (boys R^2= 0.87, RMSE 2.0L and girls R^2 = 0.80, RMSE 2.7 L) and FFM (boys R^2 = 0.87, RMSE 2.6 kg and girls R^2 = 0.82, RMSE 3.5 kg). Similar results were seen when weight was substituted by the length of lower limb (Table 7). However, the length of other segments of limbs did not improve the predictability. Combination of the impedance indices of the 3 main segments with either age or height also gave similar predictability as for the use of whole limb lengths (either upper or lower) (highlighted area in Table 7). Combination of impedance index of trunk with either upper or lower limb impedance indices also gave high predictability.

Better prediction of FM was possible when indices of specific resistivity were used in combination than in isolation (Table 8). Combined specific resistivity (upper arm + fore arm + trunk + thigh + leg) with weight gave

Table 7: Variables used to predict TBW and FFM in each gender (adjusted coefficient of determination and RMSE calculated)

	Total body water				Fat free mass			
	Male		Female		Male		Female	
	R^2	RMSE (L)	R^2	RMSE (L)	R^2	RMSE (kg)	R^2	RMSE (kg)
$II_{Whole\ Body}$	0.85	2.3	0.81	2.6	0.86	2.7	0.82	3.4
$II_{Upper\ limb}$	0.82	2.3	0.77	2.9	0.83	3.0	0.78	3.8
$II_{Lower\ limb}$	0.82	2.4	0.76	2.9	0.83	3.1	0.77	3.9
II_{Trunk}	0.79	2.4	0.59	3.8	0.8.	3.3	0.60	5.1
$II_{Upper\ limb} + II_{Lower\ limb} + II_{Trunk}$	0.87	2.0	0.80	2.7	0.87	2.6	0.81	3.5
$II_{Upper\ arm} + II_{Forearm} + II_{Trunk} + II_{Thigh} + II_{Leg}$	0.87	2.0	0.80	2.8	0.87	2.6	0.80	3.6
$II_{Upper\ limb} + II_{Lower\ limb} + II_{Trunk}$ + Weight	0.88	1.9	0.82	2.6	0.89	2.4	0.83	3.4
$II_{Upper\ limb} + II_{Lower\ limb} + II_{Trunk}$ + Height	0.87	2.0	0.80	2.7	0.88	2.6	0.81	3.5
$II_{Upper\ limb} + II_{Lower\ limb} + II_{Trunk} + L_{Upper\ Limb}$	0.87	2.0	0.80	2.7	0.87	2.6	0.82	3.5
$II_{Upper\ limb} + II_{Lower\ limb} + II_{Trunk} + L_{Lower\ Limb}$	0.87	2.0	0.81	2.7	0.88	2.6	0.81	3.5
$II_{Upper\ limb} + II_{Lower\ limb} + II_{Trunk}$ + Age	0.87	2.0	0.80	2.7	0.88	2.6	0.81	3.5
$II_{Upper\ limb} + II_{Trunk}$	0.86	2.0	0.77	2.9	0.87	2.7	0.78	3.8
$II_{Lower\ limb} + II_{Trunk}$	0.86	2.1	0.77	2.9	0.86	2.7	0.78	3.8

L: limb; II: impedance index

Table 8: Variables used to predict fat mass in each gender [adjusted coefficient of determination and RMSE (kg) calculated]

	Male		Female	
	R^2	RMSE	R^2	RMSE
ρ_{Body}	0.58	4.2	0.41	5.4
$\rho_{Upper\ Limb}$	0.43	4.9	0.30	5.8
$\rho_{Lower\ Limb}$	0.48	4.7	0.37	5.5
ρ_{Trunk}	0.62	4.0	0.23	6.1
$\rho_{Upper\ Arm} + \rho_{ForeArm} + \rho_{Trunk} + \rho_{Thigh} + \rho_{Leg}$	0.68	3.7	0.48	5.1
$\rho_{Upper\ Arm} + \rho_{ForeArm} + \rho_{Trunk} + \rho_{Thigh} + \rho_{Leg}$ + Weight	0.84	2.4	0.74	3.6
$\rho_{Upper\ Arm} + \rho_{ForeArm} + \rho_{Trunk} + \rho_{Thigh} + \rho_{Leg} + L_{Forearm}$	0.78	3.0	0.65	4.2
$\rho_{Upper\ Arm} + \rho_{ForeArm} + \rho_{Trunk} + \rho_{Thigh} + \rho_{Leg} + L_{Upper\ arm}$	0.80	2.9	0.64	4.2
$\rho_{Upper\ Arm} + \rho_{ForeArm} + \rho_{Trunk} + \rho_{Thigh} + \rho_{Leg} + L_{Lower\ limb}$	0.79	3.0	0.63	4.3
$\rho_{Upper\ Arm} + \rho_{ForeArm} + \rho_{Trunk} + \rho_{Thigh} + \rho_{Leg} + L_{Leg}$	0.80	2.9	0.62	4.4

ρ: Specific resistivity

Addition of length of upper limb or length of thigh to the combined specific resistivity did not improve the prediction the best predictability (boys $R^2 = 0.84$, RMSE 2.4 kg and girls $R^2 = 0.74$, RMSE 3.6 kg). The next best was achieved when weight was replaced by upper arm length (boys $R^2 = 0.80$, RMSE 2.9 kg and girls $R^2 = 0.64$, RMSE 4.2 kg) or fore arm length (boys $R^2 = 0.78$, RMSE 3.0 kg and girls $R^2 = 0.65$, RMSE 4.2 kg).

DISCUSSION

Bioelectrical impedance has been a useful tool in the assessment of whole body composition, changes in body composition and fluid movement (ascites, renal disease) (De Lorenzo & Andreoli, 2003). The same method has shown to be a useful tool in predicting whole body composition in Sri Lankan children (Wickramasinghe *et al.*, 2008b). Segmental BIA would be an invaluable tool in assessing body composition of individuals who cannot use the whole body BIA assessment techniques. Furthermore, this is a cost effective, non invasive and simple tool. Data evaluating the use of segmental BIA in children is scarce not only in the South Asian populations, but even in other parts of the world.

Studies have shown strong associations between the segmental impedance and the components of whole body composition in children (Fuller *et al.*, 2002a) and adults (Fuller & Elia, 1989; Organ *et al.*, 1994). As ethnicity influences the body composition, there could be differences in distribution of impedance. Therefore, use of general prediction equations across different ethnic populations without prior validation should be avoided. (Wickramasinghe *et al.*, 2008a; Deurenberg *et al.*, 2002). Body compositon in the South Asian populations differ from other ethnic groups and this population is grossly understudied. Therefore, the results of this study are important to explore the usefulness of segmental BIA in assessemnt of body compositon in this population.

The relationships that were observed between the estimated whole body composition assessment and the anthropometry as well as the segmental impedances were quite similar to the results that were seen in the group of children studied by Fuller and co workers (2002a). The impedance indices and specific resistivity also showed similar relationships and were equal or stronger in our data than what was observed in that study (Fuller *et al.*, 2002a).

The sum of segmental impedance was always higher than the whole body impedance. This was observed by Baumgartner *et al.* (1989) and it was a 16 % over estimation compared to 3 – 6.1 % observed in this study. Fuller and Elia (1989) also observed a higher value of 9 % for men and 7 – 12 % for women, which was again quite higher than the values obtained in our study. However, Organ *et al.* (1994) did not observe such an error. This could be due to the main difference in the methodologies adopted, where Organ *et al.* (1994) did not move the electrodes from one reading to the another while others did. Maintaining the same current source will help in maintaintaining the same magnitude and confuguration of the current. The heterogenity of the human body as well as the efficeincy of the contact electrodes contribute to this. Electric current always try to travel through the shortest possible route and in the whole body assessment, it passess through the lowest part of axilla. However, in the assessment of segmental impedance, in order to maintain reproducibility, shoulder electrode is placed on the acromium, which is quite further away from the floor of axilla leading to an increase in impedance (Fuller & Elia, 1989). Ineffective contact of electrodes also contributes to increase in resistance and it could be demonstrated in our results as well. The over - estimation is high, when five segmental (forearm, upper arm, trunk, thigh and leg) assessment is done (5 – 6.1 % variation) compared to three (upper limb, trunk and lower limb) segmental assessment (3 – 4 %). The electodes placed at elbow and knee joints have been contributing to this increase in resistance in the case of five segment assessment.

As there were not much regression analysis data on paediatric age group, the data were compared with the regression data published on adults. For the prediction of TBW using the whole body impedance, predictability of data from this study (boys $R^2 = 0.85$, RMSE 2.3 L and girls $R^2 = 0.81$, RMSE 2.6 L) were much higher compared to data from Organ *et al.* (1994) (men $R^2 = 0.73$, SEE 3.43 L and women $R^2 = 0.69$, SEE 2.12 L). When Organ *et al*. (1994) used the impedance indices of 3 main segments (upper limb, trunk and lower limb) in combination, it weakened the predictability of TBW in men ($R^2 = 0.67$, SEE, 3.76 L) and improvement in women ($R^2 = 0.74$, SEE 1.93 L). Contrary to the results of regression analysis by Organ *et al.* (1994), our data showed a slight improvement in boys ($R^2 = 0.87$, RMSE 2.0 L) and almost remained unchanged in girls ($R^2 = 0.80$, RMSE 2.7 L). Predictions for FM using specific resistivity was slightly weaker in our data, compared to Organs *et al*. (1994).

CONCLUSION

Overall data has shown that segmental BIA can be used for the assessment of the whole body composition of Sri Lankan children. Impedance index shows better predictability of TBW and FFM, while specific resistivity shows better prediction of FM. Combination of different variables always improved the predictability, compared to the use of variables in isolation. Prediction equations need to be developed for clinical use and it is important to select the best predictor variables. Furthermore, it should be borne in mind that the selected variables should be practical to apply in day-to-day clinical practice on an array of patients with different disabilities.

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Conflict of interest

All authors have no conflicts of interest to declare.

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