CHAPTER SEVEN
Anthropometric Measurements in Zambian Children

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1. INTRODUCTION

For field studies the use of anthropometry to assess body composition in adults and children is an ideal method. The basic equipment needed includes a hanging horizontal balance scale, a measuring tape and calipers and offer the advantage of portability and low cost. Specific equations to predict percentage body fat have been developed for groups of differing age, sex and ethnicity. The precision of this method is good (Lohman *et al.,* 1992). The standard errors of estimate are reported to be 3.6–3.9% fat for the triceps plus subscapular sites and 3.8% fat for the triceps plus calf sites (Slaughter *et al.,* 1988). Training of personnel is straightforward and the equipment is maintenance free (Ellis, 2001).

Bioelectrical impedance analysis (BIA) is another potentially convenient method for field use. The equipment is portable and relatively inexpensive. In the field, the equipment can work using a solar-charged or vehicle-charged deep-cell 12-volt battery or an electrical generator. This method is based on the principle that BIA estimates body composition based on the different conductive properties of different body tissues at various electrical frequencies. Tissues that are high in water and electrolyte content like muscle, blood and cerebrospinal fluid are highly conductive, while tissues like fat and bone are resistive to electrical conductivity. These properties of tissue conductivity, or more specifically impedance (total opposition to electrical current) are used to assess body composition. An applied current follows the path of least resistance, and charge may be temporarily stored in cell membranes as capacitance.

Impedance is a function of resistance and reactance according to the formula:

$$Z = (R^2 + Xc^2)^{0.5} \quad (1)$$

Where Z=impedance in Ω
R=resistance in Ω
Xc=capacitance in Ω

Because resistance is much greater than capacitance at the standard 50kHz frequency, it largely determines the magnitude of the impedance, and Z and R are sometimes used interchangeably. In a substance of uniform composition, resistance is proportional to the square of the path length and inversely proportional to the volume. While the living body is more complex, the volume of the different tissues can be deduced by measuring their combined resistances. (Ellis, 2001; Roche *et al.,* 1996). In practice, once the resistance has been established, a BIA analyzer uses in-built prediction equations for estimating %fat which take account of stature, mass, age and sex, and activity level.

Jurimäe *et al.* (1998) studied the differences in assessing percent body fat (% BF) in pre-pubertal White European children using six different regression equations and BIA (Bodystat-500, Bodystat Ltd. Isle of Man. U.K.). Their results showed that for this group of children the Boileau and Houtkooper equations were the most appropriate.

Caballero *et al.* (1998) developed instruments to assess body fat in American-Indian children. The authors used isotopic dilution as a reference standard. A specific equation was developed on the basis of body weight, triceps and subscapular skinfold and BIA (Valhalla Scientific Model 1990B. San Diego, CA. U.S.A.).

Lohman *et al.* (1999) used this equation as well as BIA to assess body fatness in school-age children. Their results showed that this group of children had excessive body fat.

Leman *et al.* (2003) validated the use of BIA (01Q; RJL Systems Inc., Clinton Township, MI) to assess body composition in Nigerian children and adults. The authors used total body water (TBW) determinations to develop prediction equations for this group of children and adults.

Vienna *et al.* (1998) used BIA (101/Quantum, AKERN s.r. Florence, Italy) and anthropometric measurements of height, weight and body mass index (BMI) in Ecuadorian children of African ancestry. Their findings showed BIA yielded much more information than that of the limited anthropometric measurements taken. BIA proved useful in determining body composition in school age children of different socioeconomic status and thus estimating the risk of malnutrition. Regardless of socioeconomic status, females had more fat and less total body water than males, and children of higher socioeconomic status had less fat than those of lower socioeconomic status.

VanderJagt *et al.* (2000) used BIA (Quantum, RJL, Inc. Clinton Township, MD) to assess body composition of children with sickle cell anemia in northern Nigeria. Their study showed that BIA was a useful method in assessing body composition in these

children considering the dryness and high temperatures that prevail in this region of sub-Saharan Africa.

The intention of this study, therefore, was to compare the body composition results obtained by BIA-TANITA® TBF 300A to those of three prediction equations in African children in Zambia. We hypothesised that there would be no significant difference between the body composition results obtained using anthropometric measurements and BIA-TANITA® in this group of children. To our knowledge this was the first study to use BIA-TANITA® TBF 300A in Zambian children.

2. METHODS

2.1 Subjects

This investigation involved children from five rural villages (*Chaola, Chisunga, Fusi, Katambo,* and *Mohenga*), in the Mwami catchment area of the Eastern Province, Zambia, in conjunction with a Child Survival Project funded by the United States Agency for International Development (USAID).

The sample for this particular study was drawn from a follow-up cohort study of Mwami catchment children. During the follow-up process of conducting a dietary and anthropometric assessment, the children's mothers were interviewed along with their children. Fifty children were included in this study, 23 females and 26 males. The gender for one of the children was not recorded. However, since the results of this study are of pooled data of males and females the child for whom gender is missing was included in the data analysis.

This study was conducted in primitive conditions that are the environment in which the Child Survival Project functions. Measurements were conducted inside a rural, mud, straw-thatched village hut. The temperature was hot at an estimated 27–30°C dry heat during the months of August-September 1999. Under these circumstances we had no control over the environmental conditions of humidity or temperature.

Several authors have reported the effects of ambient temperature on BIA readings. Caton *et al.* (1988) showed that ambient temperature can influence BIA readings. Skin temperature and consequently blood flow change with temperature. It has been reported that temperatures of 35°C can produce lower readings for fat mass and higher fat free mass, as compared with lower ambient temperatures. Gudivaka *et al.* (1996) had similar findings when he subjected his subjects to a temperature of 35.8°C. Liang *et al.* (2000) also concluded that a decrease or an increase in ambient temperature affects both body temperature and skin blood flow. Consequently both affect BIA readings.

Buono *et al.* (2004) studied the effects of different temperatures (15, 20, 25, 30 and 35°C) on skin blood flow (SBF) and BIA results. These authors showed that BIA results are not significantly affected by temperatures of 20 and 25°C. However at the higher temperatures resistance was inversely related to skin blood flow, and this, rather than the electrode-skin interface, affected BIA output.

2.2 Measurements

To standardize measurement procedures, the ADRA personnel and Loma Linda University postgraduate students participating in this study were trained to perform anthropometric and BIA measurements by Loma Linda University faculty members.

2.3 Anthropometry

Measurements were made according to the protocols of Lohman *et al.* (1988), with the exception that measures were made on the left side of the body. Subjects wore light-weight clothing, and had bare feet. Standing height measurements were taken using metal tape fixed to a vertical board. Measurements were taken to the nearest 0.1 cm. A Broca plane was used to mark the child's height on the measuring tape. (Perspective Enterprises. Portage, Michigan. USA).

Skinfold measurements were taken to the nearest 1 mm using Lange skinfold calipers (Cambridge Scientific Industries, Inc. Cambridge, Maryland, USA). Measurements were taken while the subjects stood in a relaxed position wearing minimal clothing. Each measurement was repeated in a set of two trials and the mean of these measurements was used for calculations. The following skinfolds were measured: Triceps: Vertical fold raised midway between the olecranon and acromion process on the posterior of the brachium. Subscapular: Measured 1 cm below the inferior angle of the left scapular inclined downwards and laterally in the natural cleavage of the skin. Medial calf: Vertical skinfold raised on the medial side of the left calf just below the level of the maximal calf girth.

For all these measurements, the children's mothers assisted in removing excess clothing from the children so that the children were wearing minimal clothing when measured. The mothers also assisted in gaining the children's cooperation for the measurements while the trained students and ADRA personnel performed the procedures. Three different equations were used to predict children's body composition. Houtkooper's Equation (2) was used to calculate fat free mass (FFM), while Lohman's (3) and Slaughter's (4) Equations were used to calculate percent fat (%Fat).

Houtkooper's Equation

$$\text{For males and females } Kg = 0.61\ S^2/R + 0.25\ wt + 1.31 \qquad (2)$$

Where S=Standing height (cm)
R=Resistance (ohms)
Wt=Kg.
(The R value given by the BIA Tanita-BIA output).

Lohman's Equation

$$\text{Males: \% Fat} = 1.21\ (\sum SF) - 0.008\ (\sum SF)^2 + I_M$$
$$\text{Females: \% Fat} = 1.33\ (\sum SF) - 0.013\ (\sum SF)^2 + 2.0\ \text{(Females)} \quad (3)$$

Where $\sum SF$=sum of Triceps and Subscapular skinfolds,

I_M=is an intercept which varies with maturation level and racial group for males. We used (−3.5) for prepubescent black children (Lohman, 1992).

Slaughter's Equation

$$\text{Females \% Fat} = 0.610\ (\text{triceps and calf skinfold}) + 5.0$$
$$\text{Males \% Fat} = 0.735\ (\text{triceps and calf skinfold}) + 1.0 \quad (4)$$

2.4 Bioelectrical Impedance

Leg to leg BIA-TANITA® TBF 300A (Tokyo, Japan) was used to assess the children's percent fat (% Fat), Kilograms (kg) of fat free mass (FFM), and total body mass (TBM). The BIA-TANITA® TBF 300A is a portable device that resembles a bathroom scale; it requires a horizontal, smooth hard surface. In this study, the device was set up inside a rural, mud, straw-thatched village hut. The subjects (wearing minimal clothing) wiped their feet and then stood upon the footplate electrodes that are located on top of the horizontal surface of the apparatus. Subjects stood in a relaxed position while the BIA measurement was taken. Two readings were taken for each subject. The mean of both measurements was used in the data analysis.

The results of BIA-TANITA® TBF 300A were compared to those obtained from Houtkooper (FFM), Lohman and Slaughter's (%Fat) equations.

3. DATA ANALYSIS

Descriptive statistical analysis was done using SPSS 10.0 version (SPSS Inc. Chicago Ill). Assumptions were met according to Pearson's correlation (normal distribution, equal variances, homogeneity, linearity between the two variables), and the accuracy of between-person variation was evaluated.

Pearson's correlation was used to test for a linear relationship between the results for FFM obtained using Houtkooper's equation and BIA-TANITA® TBF 300A. The same was done with the results for %Fat using the Lohman, Slaughter Equations and BIA results. Bland-Altman plots (Bland, 1986) were used as an alternate method of analysis.

The mean of two measurements was used in the statistical analysis. Due to the small number of subjects, analysis was done using pooled data of both males and females.

4. RESULTS

Table 1 shows the subjects characteristics. Results are presented as minimum, maximum, mean and standard deviation. Table 2 shows the Pearson correlation results

Table 1. Physical Characteristics of the Study Subjects

Variables	N	Min	Max	Mean	Std. Deviation
Height (cm)	50	91.40	140.10	107.99	7.99
Weight (kg)	50	12.60	33.50	17.79	3.33
Age (Month)	50	60	98	77.28	8.27
Gender					
Female	23	N/A	N/A	N/A	N/A
Male	26				
Missing	1				

N/A=Not Applicable

Table 2. Body Composition Correlations Between Body Composition Equations and BIA Tanita.

Equations	N	Mean±SD	*r* value	*P* value
Houtkooper's FFM (kg) vs (TANITA)		16.16±3.46	0.79	0.001
	50	15.13±2.90		
Lohman's % Fat vs (TANITA)		13.95±5.03	−0.36	0.011
	50	15.00±5.81		
Slaughter's % Fat vs (TANITA)		15.02±3.17	−0.10	0.47
	50	15.00±5.81		
Lohman's % Fat vs Slaughter's % Fat		13.95±5.03	0.76	0.0005
	5	15.02±3.17		
Houtkooper's FFM (%) vs (TANITA)	50	9.00±0.14	0.26	0.86
	500			
		15.00±5.81		

There was a significant positive correlation (r=0.79, p<0.001) between Houtkooper's Equation and BIA-TANITA® TBF 300A for FFM. However, we are aware that the Houtkooper's Equation contains the R value (resistance) in the equation. This value is given by BIA-TANITA® TBF 300A.

There was a significant negative correlation (r=−0.36, p=0.011) between Lohman's Equation for %Fat and BIA-TANITA® TBF 300A. A significant negative correlation was observed (r=−0.10, p=0.47) between Slaughter's %Fat and BIA-TANITA® TBF 300A. However, a significant positive correlation was observed between Lohman's %Fat and Slaughter's %Fat (r=0.76, p=<0.0005). When we derived %Fat from Houtkooper's Equation, we found a non-significant correlation (r=0.26, p=0.86) between this equation and BIA-TANITA® TBF 300A.

Figure 1 shows the results of a Bland-Altman plot for FFM calculated using Houtkooper's Equation and FFM measured using BIA-TANITA® TBF 300A. Many children were found to have parasitic infections and the degree of infection may have influenced their total body mass. A couple of children were found to be heavier than the majority of the group as indicated by the expected body composition by BIA-TANITA® TBF 300A calculations for height and age, this may explain the outliers.

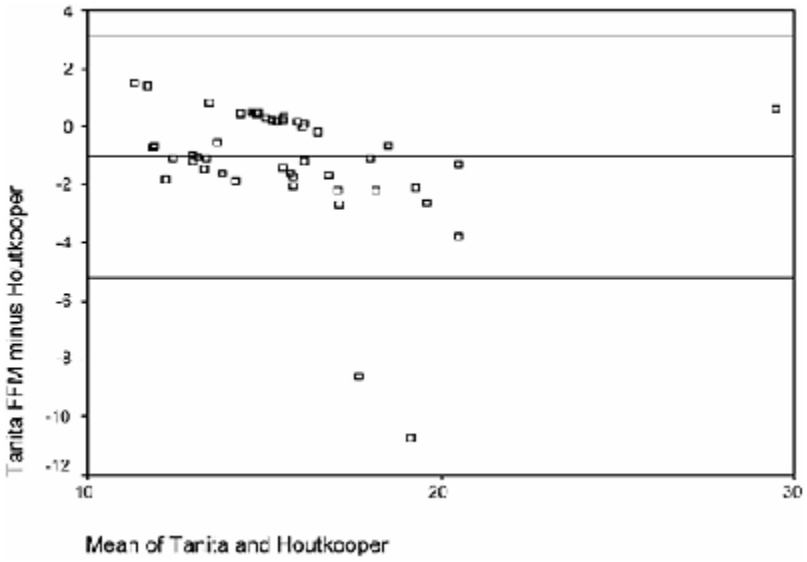


Figure 1. Bland-Altman plot showing the mean of the TANITA® and Houtkooper's equation (FFM) kg. and the difference between the two means

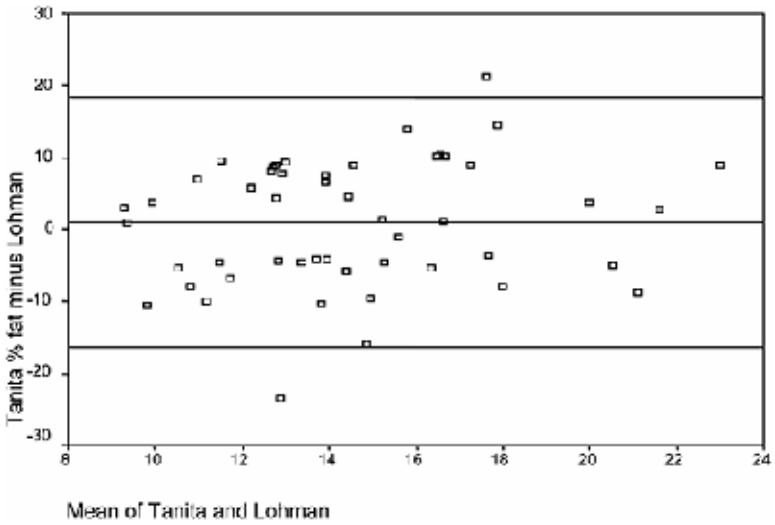


Figure 2. Bland-Altman plots showing the mean of the TANITA® and Lohman's (% Fat) equation and the difference between the two means

Figure 2 shows the results of Bland-Altman plot for % Fat using Lohman's equation and %Fat measured using BIA-TANITA® TBF 300A.

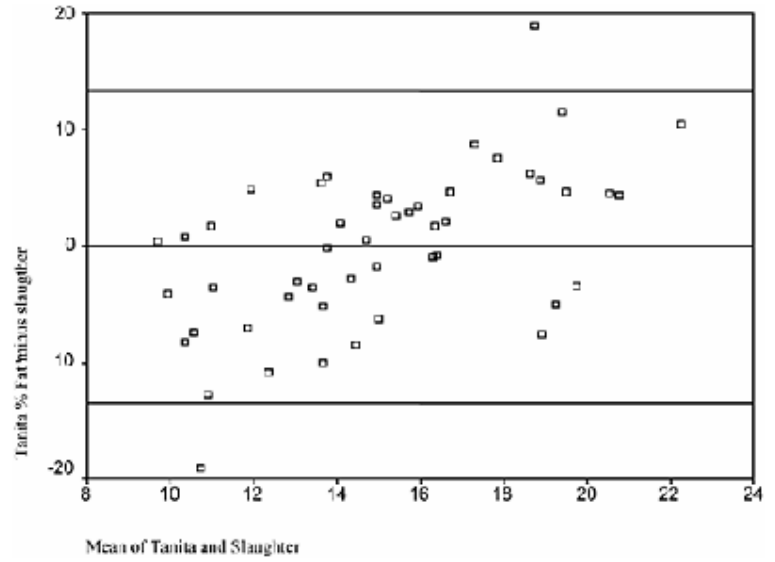


Figure 3 Bland-Altman plot showing the mean of the TANITA® and Slaughter's (%Fat) equation and the difference between the two means

Figure 3 shows the results of Bland-Altman plot for %Fat using Slaughter's equation and %Fat measured using BIA-TANITA® TBF 300A.

These last two graphs show a large variability in %fat between BIA-TANITA®

TBF 300A and Lohman's (±18%fat) and Slaughter's (±14%fat) equations.

The combination of the correlation results and the Bland-Altman plots show us that there is no agreement between methods.

5. DISCUSSION

The use of leg-to-leg BIA-TANITA® TBF 300A and different BIA and anthropometric equations to assess FFM and %Fat in children were used in this study in order to have a more efficient body composition tool for evaluating children in Zambia.

Although the results for FFM obtained using Houtkooper's Equation showed a significant correlation with those obtained with BIA-TANITA® TBF 300A, Bland-Altman plots show that there was large variability (±4 kg for children whose mean weight is 18 kg.

Our results were not in agreement with those obtained by other investigators. Jurimäe *et al.* (1998) reported results of their study conducted in 9–11 year old white children. In that study the authors compared BIA using Bodystat-500 to Houtkooper's Equation and concluded that this was an appropriate equation for use in this group of children.

The results for %fat that we obtained using Lohman's, Slaughter's and Houtkooper's equations were not comparable to those obtained with BIA-TANITA® TBF 300A as shown by the correlation results and Bland-Altman plots.

Besides temperature, other factors such as age, sex, growth, body type, and body weight may affect BIA results. Lohman *et al.* (1992) analyzed the effect of age and sex on hydration of Fat Free Body (FFB). His findings showed that with age, children and youth of both sexes experienced a decrease in hydration status. Males experienced a decrease of 3.6% and in females a decrease of 3–6%. In a prepubertal sample, these authors found the water content of the FFB to be 75% as compared to 72.5% in adults. These changes in hydration may influence BIA readings, giving lower readings for FM.

Bunc *et al.* (2000) showed that total body water (TBW) estimated by BIA (2000 M, Data Input, Germany) was higher in children than adults. The children's values decreased with age. Therefore, this will have an effect on FFM readings.

Phyllips *et al.* (2003) reported that BIA (101, RJL, Clinton Township, MI), provided accurate measurements for FFM and %FM in adolescent girls who were followed from September 1990 to June 1993

Jurimae *et al.* (2000) analyzed the effect of different somatotypes in 9–11 year old Caucasian children. Their findings showed that the mesomorphic type (robust and muscular) was the type that most influenced body resistance in both prepubescent boys and girls.

Ward *et al.* (2000) reported that BIA results may be affected by different population's body type or by ethnicity. It is not clear if the differences were due to body geometry or to electrical properties. What was clear was that body impedance exhibited population specific characteristics.

Schoeller *et al.* (2000), in their BIA study of African-Americans and Caucasians, found that excess body weight was the variable that influenced their results and not race.

All these studies point out the effect of other variables that may have influence on BIA results, which might have been the case in our study

At the time of this study (1999), there was a paucity of published work on the use of BIA measurement among general rural populations in Africa. This was one of the first studies to compare the use of BIA for body composition along with more traditional methods of anthropometric measurement in a rural setting. At the time of the study, no BIA reference data were available for children. The study was an early attempt to assess if BIA methods would work in these difficult situations. While we did expect to validate the skinfold prediction equations using BIA-TANITA® TBF 300A, due to the working conditions in the rural field, we did not reach the expected outcome. All of these factors resulted in our being unable to have confidence in the accuracy of our BIA measurements.

To our knowledge this is the first study that attempted to compare the results of the Houtkooper, Lohman and Slaughter's equations with those of leg-to-leg BIA-TANITA® TBF 300A, in Zambian children. Other investigators used other BIA devices to measure body composition in urban African children. These measured lower and upper body composition, while the device we used measured lower body composition. This fact may have also influenced the outcome of our results.

While the random error is high, the bias is small, so that using any of these methods to assess group means in a similar population may yield similar results. However, evaluation of individual levels of fatness can often be more important in making decisions for therapeutic interventions. In public health we are constantly faced with the choices for nutrition interventions based on the findings for each individual.

6. CONCLUSION

In summary, we suspect that due to the environmental conditions under which this study was conducted, the use of BIA-TANITA® TBF 300A for field use in this group of children was not validated. Therefore, we feel that the use of skinfolds to assess body composition in the rural setting of Zambia is still the preferred instrument for the field where it is impossible to control temperature, humidity and other factors.

In order to validate the use of BIA-TANITA® TBF 300A for field use in this group of Zambian children more studies are needed under controlled conditions of a laboratory setting to estimate the contribution of the separate errors which appear to have confounded the primary study aim.

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