Body Composition Estimates Using Different Measurement Techniques in a Sample of Highland Subsistence Farmers in Guatemala

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ABSTRACT This study aims at assessing the accuracy of estimates of body composition provided by bioimpedance (BIA) equations developed for U.S. populations when applied to a sample of Guatemalan farmers. If these equations were shown to have low validity, the second objective was to develop more accurate estimates of fat-free mass (FFM). One hundred males and females 19 to 45 years of age were randomly selected from four rural communities in the Western Highlands of Guatemala. Bioimpedance equations explained 59 and 33% of the variation in FFM, with a RMSE of 2.7 and 2.8 kg in males and females, respectively. Body fat (BF) predictions had a lower R^2. Using the "all possible regressions" procedure, the best subset for prediction of FFM used anthropometric and BIA variables as predictors. The best model for men and women included only anthropometric variables: 75% of the variance in FFM for men and 70% of the variance in women was explained by this model. The RMSE was 2.1 and 1.9 kg for both groups, respectively. It is concluded that FFM can be estimated from anthropometric dimensions with a high degree of accuracy and use of BIA does not provide more valid estimates.

Nutritional status is determined by the balance between food intake, utilization of nutrients, and nutritional requirements. All of these are influenced by social, biological, and behavioral factors. The final outcome of the interaction of these factors will be reflected in a specific body composition that can be measured using different methods (Garrow, 1979, 1982).

Several studies have used anthropometric dimensions either alone or in combination with other variables in an attempt to develop models to estimate body composition (Segal et al., 1988; Lukaski, 1985; Lukaski et al., 1985; Heymsfield et al., 1982; Johnston, 1982; Roche et al., 1981; Jackson and Pollock, 1978; Durnin and Womersley, 1974). However, samples have often been small and were not randomly selected; therefore, the results cannot be applied to other populations. More accurate methods have been used to estimate body composition, such as body density determination using underwater weighing. These methods are more complex than anthropometry, are more time-consuming, and require considerable subject collaboration; they are also more difficult in the field setting. Underwater weighing is a valid method that correlates well with chemical analysis of cadavers (Brożek et al., 1963), and with dynamic changes in protein–energy balance in obese subjects (Garrow et al., 1979).

Bioimpedance analysis is a relatively new method for estimating body composition. It is based on the application of an electrical current and on the different electrical conduction properties of fat and fat-free mass. This method lends itself to easy standardization, is safe and noninvasive, has a relatively low cost, and can be applied under field conditions. Thus, it has promise for field work, especially in developing countries.

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In this study, estimates of body composition obtained by means of bioimpedance analysis (BIA) and anthropometry are compared with those obtained by means of densitometry in order to validate the former. The degree with which anthropometry and bioimpedance estimates of body composition predict those generated by densitometry will be a measure of accuracy (or validity). The aims of the present study were (1) to assess the accuracy of body composition predictions in a sample of rural Guatemalan adults based upon bioimpedance equations developed for U.S. adults, and (2) to develop more accurate regression equations to predict body composition in Guatemalan farming populations (in case of low validity of these equations).

MATERIALS AND METHODS

Subjects were 50 men and 50 women, all apparently healthy, between 19 and 45 years of age, selected at random from four rural communities in the Western Highlands of Guatemala. The subjects were brought to INCAP's physiology laboratory after an overnight fast. Technical problems during residual lung volume determination resulted in the exclusion of one female and one male.

Resistance and reactance were measured using bioimpedance equipment (RJL-BIA-103), with the subjects lying on an examining table with their limbs abducted. Electrodes were placed just below the phalangeal–metacarpal joint in the middle of the dorsal side of the right hand and just below the transverse (metatarsal) arch on the superior surface of the right foot. The upper detector electrode was placed on the dorsal surface of the right hand at the midpoint between the distal radial and ulnar prominences, while the lower electrode was placed on the midpoint between both malleoli of the right leg. All measurements were made after the subject had defecated and emptied his/her bladder, without previous exercise, before they were subjected to the densitometry procedures, and in a position of complete relaxation. BIA equipment was calibrated daily using a 500-ohm resistor.

Using an empirically derived formula provided by the manufacturer of the body composition analyzer (Body Comp Bas version 8.5), fat-free mass (FFM) was estimated. Body fat mass (BF) was calculated as the difference between body weight and FFM. The variables required by the formula were weight, height, age, and sex.

Body density was assessed by underwater weighing, corrected for residual lung volume using helium dilution. Underwater weight was recorded in a forced exhalation and simultaneously with residual lung volume determination. Water temperature was constantly kept between 36 and 37°C during examinations. This method has been described previously (Flores et al., 1984; Diaz et al., 1989), and the principles underlying this technique are described elsewhere (Brozek and Henschel, 1961; Siri, 1956). In order to test the reproducibility of the measurements, a reliability test was performed for anthropometry, BIA, and densitometry. Percent of body weight as fat was calculated from four skinfolds using Durnin and Womersley (1974) equations, RJL-BIA 103 software (Body Comp Bas, version 8.5), and from body density using Siri's (1956) equation. A group of 32 members of the INCAP staff was measured on two consecutive days; no significant differences were found for day 1 vs day 2 comparisons. A high correlation and low root mean square error (RMSE) were obtained for each method; anthropometry: r=0.99, RMSE=1.1% BF; BIA: r=0.98, RMSE=1.0% BF; and densitometry: r=0.95, RMSE=1.2% BF.

Anthropometric dimensions included weight and height, circumferences of the arm, calf, and thigh, and skinfolds at the biceps, triceps, subscapular, suprailiac, abdominal, calf, and thigh locations. Abdominal circumference, mid-axillary line skinfolds at the xiphoid level, and chest and costal skinfolds were additionally measured in men. The measurements were performed by only one examiner following the procedures of Weiner and Lourie (1969), Wilmore (1969), and Wilmore and Behnke (1970). Weight was measured with a beam balance with 0.010 kg sensitivity, skinfolds were measured with a Lange caliper to the nearest 1 mm, and circumferences were measured with a metal tape to the nearest 1.0 mm sensitivity.

Regression analysis was initially performed between FFM and BF estimates obtained from bioimpedance and densitometry. Second, prediction models were developed to estimate FFM with anthropometric dimensions and bioimpedance outcomes (resistance and reactance) as predictor variables. The analysis was separately performed for males and females. The "best regression model" (SAS/STAT™, 1988) was obtained using the "all possible subsets pro-

TABLE 1. Characteristics of highland men and women in Guatemala

	Males ($n = 49$)		Females ($n = 49$)	
	X ± SD	Median	X ± SD	Median
Age (years)	28.6 ± 5.9	28.0	25.3 ± 5.5	24.0
Weight (kg)	53.9 ± 5.7	52.5	45.8 ± 4.4	46.0
Height (cm)	160.7 ± 5.0	160.0	147.7 ± 3.7	147.3
Density (g cm^3)	1.07603 ± 0.013	1.07666	1.04998 ± 0.012	1.04797
Fat (% wt)[1]	10.2 ± 5.3	9.7	21.5 ± 5.3	22.3
Fat mass (kg)[1]	5.6 ± 3.2	5.0	9.9 ± 2.9	10.2
Fat-free mass (kg)[1]	48.3 ± 4.6	47.6	35.9 ± 3.5	35.1
Resistance (ohm)	508.5 ± 36.7	504.5	590.3 ± 51.9	599.0
Reactance (ohm)	56.6 ± 4.5	57.0	60.7 ± 7.6	60.0

[1]By densitometry.

cedure" of SAS. This procedure assesses all possible combinations of independent variables (2^{p-1} equations when there are p potential variables). All independent variables measured were included in the model selection procedure. The best equation was selected from those with the lowest Schwarz Bayesian Criteria (SBC) statistics, the lowest condition number, and the highest variance explanation* (Flores, 1989). Analysis of the normality of the distribution of residuals (Shapiro–Wilks, W statistics) was also performed as an aid in identifying the best subset equation.

RESULTS

Age, weight, height, density, and impedance outcomes are presented in Table 1. The subjects were physically active adult men and women with mean ages of 28.6 and 25.3 years, respectively. The relationship between weight and height was similar for both sexes, with mean BMIs (weight/height^2) of 20.87 and 20.99 (kg/m^2), respectively. On average, males were 13 cm taller than females.

Prediction of FFM and BF using the manufacturer's bioimpedance formula gave low R^2 coefficients ($R^2 \leq 0.59$) and high RMSE, especially for BF estimates (Table 2). The variables which were most significantly correlated with FFM in males and females, respectively, were weight (R=0.82, 0.75), arm circumference (R=0.69, 0.55), calf circumference (R=0.67, 0.70), and thigh circumference (R=0.67, 0.58). Resistance, but not reactance, was also significantly correlated with FFM (R=−0.44, −0.35).

The best subset regression equations for FFM estimates in males and females are shown in Table 3. It was possible to explain 75% of the FFM variance in men and 70% in women. The estimated equation for men has no collinearity problems and the residuals are normally distributed. The condition number of the estimated equation for women indicates collinearity, but the residuals are normally distributed.

DISCUSSION

The females group had an adequate amount of fat, but men were lean, probably due to hard physical work, and a history of mild-to-moderate undernutrition. Mean relative fat mass in men is at the lower end of the distribution described for normal males in the literature (McArdle et al., 1986). Mean values of resistance but not reactance in men were significantly higher (P 3 0.05) than those reported by others in the U.S. (Segal et al., 1985, 1988; Lukaski et al., 1985, 1986), but were comparable to studies reported in Guatemalans (Guzman et al., 1987; Elsen et al., 1987). Resistance and reactance in women compare well with previous studies in the U.S. (Segal et al., 1985, 1988; Lukaski et al., 1985, 1986) and Guatemala (Siu et al., 1987). Correlations between BIA and densitometrically determined body composition are usually higher than 0.8–0.9 in normal to overweight populations (Segal et al., 1985, 1988; Lukaski et al., 1985, 1986), but not in lean groups of subjects with less than 10% BF where correlations of 0.38 and errors equivalent to 4.6% BF have been reported by Keller and Katch (1985) and Graves et al. (1987), respectively.

*Schwarz Bayesian Criteria (SBC): Used to select a model with the minimum error sum of squares calculated for each model separately, and choosing the one which provides the maximum likelihood (Schwarz, 1978; Judge et al., 1980). The condition number measures the degree of collinearity of the matrix of predictors.

TABLE 2. Regression statitics obtained for predictions of FFM and BF using BIA[1] compared to densitometry among highland Guatemalan men and women

Sex	Fat-free mass (kg)			Body fat (kg)		
	R^2	RMSE (kg)	CV[2] (%)	R^2	RMSE (kg)	CV[2] (%)
Males	0.59	2.74	5.6	0.27	2.62	49.4
Females	0.33	2.78	7.8	0.33	2.34	23.6

[1]From RJL equations developed for U.S. subjects.
[2]Coefficient of variation = RMSE mean × 100.

TABLE 3. Best subset regression equations to estimate FFM (kg) in a group of highland Guatemalan farmers

	Males (n = 46)[1]	Females (n = 49)
Mean	48.4 kg	35.9 kg
R^2	0.77	0.73
R^2 adj.	0.75	0.70
RMSE	2.15 kg	1.91 kg
CV	4.4%	5.3%
Condition No.	35.46	102.11

Variable	Regression coefficient[2]	Standard error	Variable	Regression coefficient[2]	Standard error
Intercept	10.322	3.59	Intercept	1.843	6.58
Abdominal skinfold (mm)	−0.241	0.08	Biceps skinfold (mm)	−0.724	0.24
Thigh skinfold (mm)	0.528	0.19	Calf circumference (mm)	1.080	0.28
Weight (kg)	0.751	0.07	Thigh circumference (mm)	−0.572	0.21
Calf skinfold (mm)	−0.857	0.34	Thigh skinfold (mm)	0.231	0.09
			Weight (kg)	0.590	0.14

[1]Three subjects with incomplete anthropometry.
[2]All regression coefficients statistically significant ($P < 0.05$), except for the females group intercept.

Several authors (Lukaski, 1985; Lukaski et al., 1985; Segal et al., 1985, 1988; Hoffer et al., 1969) have reported significant relationships between the height^2/resistance ratio and FFM. This ratio was not included as a predictor variable in the model, since in the same population the effect of resistance is minimal and is mediated through the inclusion of height in this index (Diaz et al., 1989).

Several techniques are available to estimate body composition. Anthropometry appears to be most appropriate for the field setting and bioimpedance seems potentially useful. However, bioimpedance equations based upon studies of U.S. subjects and applied to highland Guatemalans provided inaccurate estimates of FFM and BF compared with densitometry. Other authors have reported similar findings using TOBEC and deuterated water as the reference techniques (Segal et al., 1985; Kushner and Schoeller, 1986).

As noted by Lohman (1981) and Katch and Katch (1980), one of the problems with regression equations to estimate body composition is that the reference populations used to develop such formulas are not randomly selected. Other equations based upon bioimpedance and anthropometry have been published (Lukaski et al., 1986; Pasco and Rutishauser, 1985; Segal et al., 1985, 1988). Our results indicate that models for estimating body composition based upon studies of U.S. subjects are not appropriate for Guatemalan adults.

Although bioimpedance is a simple technique with relatively low cost and acceptable to the subjects, its measurements, resistance and reactance, did not improve FFM prediction in Guatemalan adult males and females. Resistance was selected in the group of best subsets only for men, but it did not add to the explanation of the variance (based on the adjusted R^2). There was also a significant increase in the condition number (from 35.5 to 105.8), indicating that collinearity was introduced by the inclusion of resistance. Thus, bioimpedance did not contribute any additional information to the prediction model based solely on anthropometry in a subsistence agricultural population in Guatemala. Anthropometric dimensions are relatively easy to obtain in the field. In contrast, the bioelectrical impedance technique relies on standard conditions of skin temperature and humidity, which are difficult to control under field conditions.

Densitometry is often used as the "gold standard" in body composition research. It is necessary to note that possible deviations from the commonly used constants to estimate relative fatness. BF and FFM by densitometry have little importance for predictions in normally sedentary populations (Lohman, 1984). However, they may have a significant effect on predictions in physically active populations (Roche, 1987). Roby et al. (1986) in elite U.S. swimmers, and Snyder et al. (1986) in rats, both reported that physical training can modify the bone density. Thus, it is possible that the FFM composition in Guatemalan subsistence farmers could have density values different from the assumed constant of 1.1 g/cm^3, but this cannot be ascertained from the available information in this study group. There is also the possibility that the composition of FFM is altered in chronically undernourished populations.

With the data from this study, it was possible to develop more accurate and more precise estimates of body composition compared to those obtained with prediction equations developed in U.S. populations. However, inferences from our equations must be made with caution, specifically for women due to mild multicollinearity. This was to be expected because all variables contain quantitative information related to BF and/or FFM.

In conclusion, specific combinations of anthropometric dimensions provide valid estimates of body composition in Guatemalan adults. Further, in this specific population use of bioimpedance provides no improvements in the development of FFM prediction equations.

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