Preliminary bioelectrical impedance analysis (BIA) equation for body composition assessment in young females from Colombia

J C Caicedo-Eraso1,2, C H Gonzalez-Correa1, C A Gonzalez-Correa1
1 Research Group on Electrical Bioimpedance, University of Caldas, Colombia
2 Department of Systems and Informatics, University of Caldas, Colombia
E-mail: julioc.caicedo@ucaldas.edu.co

Abstract: A previous study showed that reported BIA equations for body composition are not suitable for Colombian population. The purpose of this study was to develop and validate a preliminary BIA equation for body composition assessment in young females from Colombia, using hydrodensitometry as reference method. A sample of 30 young females was evaluated. Inclusion and exclusion criteria were defined to minimize the variability of BIA. Height, weight, BIA, residual lung volume (RV) and underwater weight (UWW) were measured. A preliminary BIA equation was developed ($r^2=0.72$, SEE=2.48 kg) by stepwise multiple regression with fat-free mass (FFM) as dependent variable and weight, height and impedance measurements as independent variables. The quality of regression was evaluated and a cross-validation against 50% of sample confirmed that results obtained with the preliminary BIA equation is interchangeable with results obtained with hydrodensitometry ($r^2=0.84$, SEE=2.62 kg). The preliminary BIA equation can be used for body composition assessment in young females from Colombia until a definitive equation is developed. The next step will be increasing the sample, including a second reference method, as deuterium oxide dilution ($D_2O$), and using multi-frequency BIA (MF-BIA). It would also be desirable to develop equations for males and other ethnic groups in Colombia.

1. Introduction

Total body water (TBW) by isotope dilution, hydrodensitometry, magnetic resonance imaging (MRI), computerized tomography (CT) and dual-energy X-ray absorptiometry (DXA) provide precise and reliable measurements of body composition and could be considered as reference methods for in vivo body measurements [1]. However, cost, accessibility, complexity and the radiation exposure with DXA, MRI and CT limit the use of these techniques [1,2]. BIA is based on measuring tissue conductivity and the relation between the volume of the conductor and its electrical impedance [3]. BIA is a simple, safe, noninvasive, relatively inexpensive method that is practical and suitable for individual use, large-scale researches and field studies in the community [4,5]. However, practice has shown that a prediction BIA equation developed for one population are valid for that specific population and can accurately predict body composition, but it is not valid when applied to a different ethnic group [6,7]. A previous study showed that available BIA equations in the literature are not suitable for our population [7]. Therefore, the purpose of this study was to develop and validate a preliminary BIA equation for body composition assessment in young females from Colombia.
2. Materials and methods

2.1. Subjects
The methods, classified as minimum risk by the Colombian Ministry of Health, were approved by the Bioethics Committee of the University of Caldas. Variations in body composition related to gender, age, ethnicity and genetic influence which affect BIA measurements [5,6] were minimized by using an adequate protocol [8] and selecting a homogeneous group of young females [5]. A group of 30 young females was evaluated. The purpose and procedures of the study were explained to the volunteers and the inclusion/exclusion criteria were verified after completing a questionnaire. Afterwards, the volunteers signed an informed written consent. The same subjects and the same measurement data were used in other study to show that available BIA equations in the literature are not suitable for our population [7]. Characteristics of subjects by mean and standard deviation (SD) are shown in table 1.

| Variables         | Mean | SD  |
|-------------------|------|-----|
| Age (years)       | 20.4 | 2.0 |
| Height (cm)       | 158.1| 4.8 |
| Weight (kg)       | 54.8 | 8.0 |
| BMI (kg/m²)       | 21.9 | 2.7 |

2.2. Data acquisition
Measurements were performed in one session early in the morning to minimize environmental [9] and biological [6] variations. Relative humidity (RH) (70.5 ± 3.5%) and environmental temperature (20.5 ± 1.0 °C) were measured with a thermo-hygrometer (13307 by DeltaTrak®, ±0.1 °C / ±1% RH) and controlled with an electric heater (BFH416 by Bionaire™) and a dehumidifier (BMD100 by Bionaire™). Volunteers were asked to comply with the following requirements before the test: 48 hours without drinking alcohol, 12 hours without vigorous exercise and 12 hours of fasting but keeping normal water hydration. All subjects were asked to evacuate their bladder and colon 30 minutes before the tests and were evaluated out of menses [5,10]. Other possible sources of error like hydration status, subject position, limb abduction, electrode position, wearing jewelry and skin alcohol use, were also controlled in this study [5,10,11]. All volunteers wore underwear and a hospital gown.

2.3. Anthropometric measurements
Height (S) (Heightronic-235 by Seca®, ±0.01 cm) and weight (W) (PP2000 by Icob-Detecto®, ±0.1 kg) were measured twice, and a third measurement was taken if it was found a difference greater than 0.5 cm or 0.1 kg respectively [12].

2.4. BIA measurements
Bioelectrical impedance was measured (Hydra 4200 by Xitron Technologies®), using the manufacturer's recommended electrodes (292-STE by Impedimed®), on the dominant side of body for three times at the end of an exhalation on a nonconductive surface. Raw resistance ($R_{50}$) and capacitive reactance ($Xc_{50}$) at 50 kHz data were used. Subjects remained in a supine position by 5 minutes and BIA measurements were made between minutes 6 to 10, with the arms comfortably separated from the body 15 degrees, and the legs comfortably separated about 45 degrees [5,13]. Dorsal hand and anterior foot surfaces were cleaned with alcohol and dried with a paper towel [5]. For reproducible measurements, four landmarks were made for the placement of the electrodes: midline between prominent ends of radius and ulna of wrist, midline of third metacarpal-phalangeal joint on dorsal hand surface, midline between the medial and lateral malleolus of ankle and midline of third metatarsal-phalangeal joint on anterior surface of foot [5,13]. Current was applied at distal electrodes and voltage was measured at proximal electrodes [5,13]. Distance between current and voltage...
electrodes was always greater than 5 cm [5]. A blanket was used for comfort and homogeneous skin temperature [5,14].

2.5. Hydrodensitometry measurements
This technique obtains the body density and implies measuring RV and UWW. RV was measured by the nitrogen washout technique (Quark PFT-2 by COSMED, ±0.01 L) and taking the average of two measurements whose difference was less than 100 cc [15]. UWW was measured (PROGAN-1500SS by Prometalicos, ±0.001 kg) within a tank filled with water (35.0 ± 2.0 °C) and taking the average of two measurements whose difference was less than 100 gr. Subject was in sitting position and wore a form-fitting swimsuit and a ballast weight in the waist [16]. Body fat (BF) was obtained applying the model of two components by Siri equation [17].

2.6. Statistical methods
The mean and the standard deviation (SD) were used to evaluate the characteristics of subjects and laboratory conditions. A preliminary BIA equation was developed by multivariate normal distribution, stepwise multiple regression analysis with multiple and partial correlation coefficient with FFM as dependent variable and W, S and impedance measurements $R_{50}$ and $X_{c50}$ as independent variables. Quality regression was evaluated by coefficient of determination $r^2 \geq 0.60$, SEE<2.7 kg, Fisher analysis of variance F≤1%, Malows index Cp, still valid Cp≥1, reliability of 95%, and statistical power PW≥80%. A cross-validation against 50% of the sample was used and a paired Student t-test and the Bland & Altman analysis [18] were used to determine significant differences ($p<0.01$) against hydrodensitometry and only SEE lesser than 2.7 kg was accepted as valid [19].

3. Results
Six predictors were analyzed: S, W, $R_{50}$, $X_{c50}$, $S^2$ and $S^2/R_{50}$. A preliminary equation (1) was developed to determine FFM (and BF) for young females from Colombia by stepwise multiple regression analysis. BF was determined by subtracting FFM from W. Equation (1) had $r^2=0.72$ (r=0.85), SEE=2.48 kg and F=0.05%; with a PW of 80%, IC of 95% and Cp=5.

$$FFM = 0.240W + 0.022R_{50} + 0.118X_{c50} + 0.939\frac{S^2}{R_{50}} - 34.09$$

A cross-validation was performed with 50% randomly selected subjects and SEE of BF was 2.62 kg with $r^2=0.84$ (r=0.92, p<0.0001) (figure 1). Paired Student’s t-test ($p=0.57$) and Bland & Altman plot (figure 2) show no significant difference between BF obtained with the preliminary equation (1) against BF obtained with hydrodensitometry.

![Figure 1. Regression of BF-Hydrodensitometry by BF-BIA (n=15).](image1.png)

![Figure 2. Bland & Altman plot of BF-Hydrodensitometry against BF-BIA (n=15).](image2.png)
4. Discussion and conclusion
BIA has higher precision and accuracy than anthropometric techniques [4, 5] if the proper equation is available [6] and an adequate protocol are used [8]. Additionally, cost and complexity is much smaller than the reference techniques [1,5]. Single frequency BIA (SF-BIA) was used as Moon et al (2013) found good agreement between DXA and SF-BIA (50 kHz) measurements when estimating FFM and BF [20] and Haas et al (2012) determined also that SF-BIA agreed well with D₂O to estimate TBW [21]. Furthermore, in 2013, SF-BIA equations to prediction of FFM still are developed [22]. The preliminary BIA equation met the proposed evaluation criteria and it could be used for estimating FFM and BF in young females from Colombia until a definitive equation is developed. The next step will be to improve r², PW and SEE, by increasing the sample, including a second reference method, as D₂O, and using MF-BIA. It would also be desirable to develop equations for males and other ethnic groups in Colombia. Maybe, in the future, the specificity of the population would be of minor importance due to the recent developments of segmental BIA with 8-electrodes [23]. However, the development of specific equations is still needed when using whole-body BIA with 4-electrodes [7].

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