Bioelectrical impedance analysis (BIA) equations validation against hydrodensitometry in a Colombian population

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Abstract: Several studies have shown that the accuracy of BIA results depends on ethnicity, age, gender, hormonal and genetic variations and, so far, there are not specific equations for Colombian population. The purpose was to evaluate reported BIA equations to determine their usefulness in body composition assessment in young females from Colombia using hydrodensitometry as the reference method. A sample of 30 young females was evaluated. Inclusion and exclusion criteria were defined to minimize the variability of BIA. Height, weight, multi-frequency BIA, residual lung volume (RV) and underwater weight (UWW) were measured. Five BIA equations met the inclusion criteria of this study. Three equations overestimated and two equations underestimated body fat (BF). Paired Student t-test and Bland and Altman analysis (p<0.05) showed significant differences in four BIA equations. However, all standard error of estimate (SEE) to BF was greater than 2.7 kg. This study showed that the five selected BIA equations are not valid for estimation of body composition in young females from Colombia. It is recommended to develop BIA equations to improve BF fat assessment in our population.

1. Introduction
The high prevalence of overweight and obesity in adults in Colombia [1] makes it necessary to have more appropriate methods for nutritional assessment of people with these diseases. Body composition can be determined by numerous methods, as hydrodensitometry, considered as reference method for in vivo measurements, but a better accuracy involves higher costs and complexity, which would limit its use for large-scale research in the community [2]. 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 [3]. Variables as gender, age, ethnicity, medical and physiological conditions, affect the predictive validity of BIA equations [4,5]. This has resulted in a variety of BIA equations developed for populations varying in one or more of these variables [3,5]. Before undertaking a new study to develop a specific population equation, a mandatory step is to validate the existing BIA equations since manufacturer [6] or reported BIA equations may be suitable [7,8] or not [9,10] for a different population for which they were developed. The purpose of this study was to evaluate reported BIA equations to determine their usefulness in body composition assessment in young females from Colombia, using hydrodensitometry as the reference method.

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 that affect BIA measurements [4,5] were minimized by using an adequate measurement protocol [11] and selecting a homogeneous group of young females [1,5]. A sample 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. Characteristics of subjects by mean and standard deviation (SD) are shown in table 1. The same subjects and the same measurement data were used in other study to develop a preliminary BIA equation for our population [12].

| Variables (n=30) | 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 [13] and biological [4] 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 [5,14]. Other possible sources of error like hydration status, subject position, limb abduction, electrode position, wearing jewellery and skin alcohol use, were also controlled in this study [5,14,15]. All volunteers wore underwear and a hospital gown.

2.3. Anthropometric measurements
Height (Heightronic-235 by Seca®, ±0.01 cm) and weight (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 [16].

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 $R_{50}$ and $X_{50}$ data were stored in a computer. 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 [5,17]. 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 [5,17]. Current was applied at distal electrodes and voltage was measured at proximal electrodes [5,17]. Distance between current and voltage electrodes was always greater than 5 cm [5]. A blanket was used for comfort and homogeneous skin temperature [5,18].

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 0.1 L [19]. UWW was measured (PROGAN-1500SS by Prometalicos, ±0.001 kg) within a tank filled with water (35.0 ± 2.0 ºC) and taking the average of two measurements whose difference was less than 0.1 kg [20]. Subject was in sitting position and wore a form-fitting swimsuit and a ballast weight in the waist [20]. BF was obtained applying the model of two components by Siri equation [21].

2.6. Selected BIA equations.
The criteria for BIA equation selection were: they have been developed for young females using hydrodensitometry as reference technique, a coefficient of determination ($r^2$) greater than 0.60 and a SEE reported by the authors, lesser than 2.7 kg, considered as acceptable in BF prediction [22].

2.7. Statistical methods
Mean and SD were used to evaluate the characteristics of subjects and laboratory conditions. The difference between BF obtained in our population with each BIA equation against the results obtained with hydrodensitometry was evaluated by SEE, paired Student’s t-test (p<0.05) and the graphical method of Bland and Altman [23]. Finally, the equation meeting the three criteria was considered valid for the target population of this study.

3. Results
Five BIA equations met the inclusion criteria and the results are shown in table 2. All SEE were greater than 2.7 kg (table 2). Paired Student’s t-test (table 2) and Bland and Altman plots (figure 1) showed significance difference; except with Lukaski et al, 1986 equation, which showed no significant differences; however, the SEE was greater than 2.7 kg.

| Equation                  | SEE (kg) | Significant difference |
|---------------------------|----------|------------------------|
| Reported by author        | Colombian young female | $P_t$ | Bland and Altman |
| Lukaski et al, 1986       | 2.06     | 3.63$^{(+)\text{+}}$ | 0.56 | Not |
| Segal et al, 1988         | 2.43     | 3.82$^{(+)\text{+}}$ | 0.0002 | Yes |
| Deuremberg et al, 1991    | 2.63     | 5.66$^{(-\text{\text{-}})}$ | < 0.0001 | Yes |
| Lohman, 1992              | 2.10     | 3.49$^{(-\text{\text{-}})}$ | 0.001 | Yes |
| Xitron Technologies       | 0.96     | 4.13$^{(+\text{+}}$ | < 0.0001 | Yes |

(+\text{+}) overestimation and (-\text{-}) underestimation

Figure 1. BF obtained by BIA equations against BF obtained by hydrodensitometry (n=30). (a) Lukaski et al, 1986, (b) Segal et al, 1988, (c) Deuremberg et al, 1991 (d) Lohman, 1992, (e) Xitron Tech.
4. Discussion and conclusion
Practice has shown that a BIA equation developed for a specific population may or may be not useful for others. The five selected BIA equations showed unacceptable SEE. In this study, use of the specific equation for our population continues to be an important issue for BIA results. It is possible that in the future, the new developments of the SBIA allow the specific population equations to be minor an issue [25]. While models and systems of BIA with 4-electrodes to assess body composition remain [26], and before embarking on the development of new equations, validation of existing equations is highly recommended. In conclusion, five chosen BIA equations against hydrodensitometry were not valid to estimate BF in young women in Colombia and the development of specific in young women in Colombia equation is recommended.

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