



Original / *Obesidad*

A comparison of dual energy X-ray absorptiometry and two bioelectrical impedance analyzers to measure body fat percentage and fat-free mass index in a group of Mexican young women

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Abstract

Introduction: Studies of obesity require the estimation of fat mass (FM) and fat-free mass (FFM); therefore it is important to validate methods that evaluate these measurements.

Objective: We sought to compare two different bioelectrical impedance analysis systems (BIAs) to estimate FM and FFM using dual-energy X-ray absorptiometry (DXA) as reference.

Methods: We used a cross-sectional design. We evaluated FM and FFM using DXA and two types of BIA equipment: a foot-foot system (FFS) and a hand-foot-system (HFS). We conducted paired analysis (paired t-test). We used Bland-Altman plots to assess the relationships between FM and FFMI, limits of agreement were constructed (CL)

Results: A total of 175 female students (22.9 ± 2.2 years-old) participated in the study. The paired analysis showed significant differences between the mean value of body fat percentage (BF%) estimated by BIA equipment compared to DXA (FFS = 28.7%, HFS = 34.4% and DXA = 35.3%). The mean difference between the HFS and DXA of BF% was -0.96, (CL -5.29, 7.20). For the FFS, the mean difference was -6.69, (CL -0.29, -13.09). The paired analysis revealed significant differences between the estimates of FFMI by BIA compared to DXA (FFS = 16.29, HFS = 14.95, DXA = 14.18). The mean difference between HFS and DXA was 0.78, and (CL -2.27, 0.72) whereas the FFS mean difference was -2.11 (CL -3.73 -0.49).

Conclusion: A different magnitude of bias was observed between the BIA equipment arrays. The HFS appears to be more reliable than the FFS used, particularly in obtaining FFMI in young women.

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Key words: *Body composition. Body fat. Fat-free mass index. BIA. DXA. Validation*

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COMPARACIÓN DE LA ABSORCIOMETRÍA DE RAYOS X DE ENERGÍA DUAL Y DOS ANALIZADORES DE IMPEDANCIA BIOELÉCTRICA PARA MEDIR EL PORCENTAJE DE GRASA CORPORAL Y EL ÍNDICE DE MASA LIBRE DE GRASA EN UN GRUPO DE MUJERES JÓVENES MEXICANAS

Resumen

Introducción: Los estudios de obesidad requieren estimación de masa grasa (FM) y masa libre de grasa (FFM).

Objetivo: Comparar dos equipos de impedancia bioeléctrica (BIA) para estimar FM y FFM usando absorciometría de rayos X de energía dual (DXA) como referencia.

Métodos: Estudio transversal. FM y FFM fueron evaluados por DXA y BIA: sistema pie-pie (FFS) y sistema mano-pie (HFS). Se realizaron pruebas t pareadas, coeficientes de correlación y análisis de Bland y Altman. Límites de acuerdo fueron calculados (CL).

Resultados: Fueron estudiadas 175 mujeres ($22,9 \pm 2,2$ años). Hubo diferencias significativas entre el promedio del porcentaje de grasa estimado por los equipos de BIA en comparación con DXA (FFS = 28,7%, HFS = 34,4% y DXA = 35,3%). La diferencia de medias del porcentaje de grasa entre HFS y DXA fue -0,96, (CL -5,29, 7,21). La diferencia de medias para FFS fue de -6,69, (CL -0,29, -13,09) Hubo diferencias significativas entre las estimaciones de FFMI por BIA y DXA (FFS = 16,29, HFS = 14,95, DXA = 14,18). La diferencia de medias entre HFS y DXA fue = 0,78, (CL -2,27, 0,72) y la diferencia de medias de FFS fue -2,11: (CL -3,73, -0,49).

Conclusiones: Niveles diferentes de sesgo se observaron entre los equipos de BIA. El HFS parece ser más confiable que el FFS, sobre todo en la obtención de FFMI en mujeres jóvenes.

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Palabras clave: *Composición corporal. Grasa corporal. DXA impedancia bioeléctrica. Validación.*

Abbreviations

BIA: Bioelectrical impedance analysis.
BMI: Body mass Index.
BF%: Body fat percentage.
DXA: Dual-energy X-ray absorptiometry.
HFS: Hand-to-foot system.
FFM: Fat-free mass.
FFMI: Fat-free mass index.
FM: Fat mass.
FFS: Foot-to-foot system.

Introduction

The prevalence and incidence of obesity have rapidly increased in both developed and underdeveloped countries; the National Survey of Health and Nutrition 2012 in Mexico showed that the prevalence of obesity was 35.8% in young women¹. The obesity trends in young adults should be monitored to avoid health problems in their future². The increase in body fat could promote the development of chronic diseases such as hypertension, dyslipidemia, disturbed glucose tolerance, diabetes mellitus, and coronary heart disease^{3,4}. Body fat mass should be assessed to develop preventive programs at a young age.

In the clinical and epidemiological field to study obesity it is important to assess not only the anthropometric measurements such as body weight, body mass index (BMI), waist circumference, and waist-to-hip ratio, because these measurements do not reflect body fat mass⁵. For this reason, researchers have developed different methods to estimate body composition, including magnetic resonance imaging (MRI), dual-energy absorptiometry X-ray (DXA), air-displacement plethysmography and bioelectrical impedance analysis (BIA)⁶.

The fat-free mass index (FFMI) offers better specificity, because this index is based on fat-free mass and not body weight, which is composed of both fat and lean mass⁷. DXA is an accepted method to measure body composition, using a three-compartment model: fat mass, fat-free mass, and total mineral content⁸. This technique has been validated against other direct methods such as neutron activation in vivo, total body potassium, and hydrodensitometry^{9,10}. This technique is highly recommended by *The European Society of Clinical Nutrition and Metabolism* as a reference method in studies to determine body composition¹¹. However, the use of this method is limited due to its high cost and the fear of radiation emitted in the course of a DXA study, although the radiation is low—even lower than a standard chest X-ray.

By contrast, the BIA method is widely used in clinics, sports medicine, and weight-reduction programs; it is accessible, minimally invasive, and does not require extensive clinical training¹². BIA evaluates the resistance of an electric current exerted across the fat-free mass due to its high water and electrolytes (sodium and potassium) content. BIA techniques are based on

the notion that tissues rich in water and electrolytes are less resistant to the passage of electricity than adipose tissue¹²; it is therefore based on a single body-resistance parameter and not on a direct measure of body components such as fat mass or fat-free mass.

It is thus a doubly indirect technique that requires the use of equations to estimate the body fat. The validity and reliability of the equations depends on the population characteristics and the reference method used. Ideally, the reliability of the methods should be tested before being used on a different sample.

Some reports have compared the percentage of body fat obtained by BIA with those obtained through other methods of reference, but the results are contradictory¹³⁻¹⁵. Several studies showed that the percentage of body fat is overestimated¹⁶, whereas others suggested that BIA underestimates body fat percentage¹⁷⁻¹⁸. Additionally, other reports have compared body composition data between BIA and DXA and have shown different limits of agreement¹⁹⁻²⁰.

In Mexico there is a lack of information on body composition on young groups. There are no published works that show the results of BIA validation in this population group. The aim of this study was to compare two different BIA equipments to estimate FM and FFMI, using DXA as the method of reference in a group of Mexican young women.

Materials and Methods

Participants

We performed a cross-sectional study on a convenience sample of 188 students aged 18 to 30 years old enrolled in their last year of undergraduate nutrition sciences at Universidad Autonoma Metropolitana-Xochimilco. Each participant signed an informed consent form. We excluded 13 students because their data were incomplete.

Anthropometry

We asked all participants to fast for twelve hours before being measured. We weighed the subjects in standardized light clothes and without shoes. We measured the participants' height in centimeters using a stadiometer (SECA) and their weight using an integrated scale in the BIA equipment (*Tanita BC-418*).

Body composition

Measurements by dual energy x-ray absorptiometry (DXA)

We used DXA equipment (Lunar Prodigy Advance®; GE Medical Systems, Madison WI) to analyze

body composition: fat mass, fat-free mass and bone mineral densities; we obtained the FFMI using the formula: FFM/height². We asked the participants to remove all metal objects to ensure accuracy of the measurements, and the students lay in a supine position during DXA assessments. Whole body composition analysis provided data of different anatomical regions of interest. We calibrated the equipment each day according to the manufacturer's instructions²¹.

Measurements by bioelectrical impedance analysis

We used a *foot-to-foot BIA system (FFS) (Tanita BC-418, Tanita Corp., Tokyo, JapanTM)* immediately after the DXA study. The subjects followed the standard BIA guidelines: light clothes, standing erect and barefooted on the analyzer's footpads, which were previously cleaned with isopropyl alcohol. The electric current was then supplied from the electrodes on the tips of toes and fingers and the machine measured the voltage on the heels of both feet and the near sides of both hands. Before the valuation, the participants were to fast for 12 hours and avoid vigorous physical exercise and alcohol intake. Measurements began when the subjects placed their hands on the grips after wiping their feet and standing on the weighing platform. Body resistance was reported in Ohms.

Hand to foot BIA system (HFS) (RJL Quantum III, Detroit Michigan, USA). The electrodes in this system are placed on the hand and foot on the same side of body. Measurements were carried out with the subject lying in a supine position on a flat surface. One of the electrode's edges is placed on the right hand on an imaginary line bisecting the ulnar head, proximal to the third metacarpophalangeal joint (positive); the second electrode edge is placed on the right foot on an imaginary line bisecting the medial malleolus (negative). Before the valuation, the participants were to fast for 12 hours and avoid vigorous physical exercise and alcohol intake.

Body composition data included FM (kg), BF%, and FFMI (kg) measures obtained by DXA and by BIA. All participants were assessed at the Unit of Body Composition and Energy Expenditure located within the facilities of the campus.

Statistical analysis

We used a paired Student's t-test to compare the results of the BIA with DXA for body fat percentage and fat-free mass index and applied the Pearson correlation coefficient between the BIA and DXA results. We constructed a Bland and Altman plot to detect bias in body composition measurements. To detect a possible trend in the differences between methods, we constructed another plot applying a linear relationship in the paired difference between DXA and BIA and paired means of methods for body fat percentage. We also obtained 95% confidence limits of agreement (CL). P-values < 0.05 were statistically significant. We performed the data analysis using the STATA V12 statistical package (StataCorp LP).

Results

A total of 175 female college students with a mean age of 22.9 (± 2.2) years old participated in the study. The mean values of weight and height were 58.06 (± 11.4) kg (range: 41.2-119.2) and 1.58 (± 0.06) m (range: 1.44-1.74 m), respectively. The mean value of BMI (kg/m²) was 23.1 (± 4.2) with a range from 16.9 to 47.8 kg/m². According to WHO classification, 66.2% were in a normal BMI category, 8.0% presented low weight, 20.0% were overweight and 5.7% were obese. The results of the body composition measurements with the different methods applied are shown in table I.

Fat mass

Body fat mass percentage by DXA analysis was 35.36% (± 7.0); the mean body fat mass was 20.3 kg (± 8.6) (table I). The paired comparison of BF% between DXA and HFS showed that this percentage was slightly underestimated by HFS, (35.36% DXA vs 34.40% BIA-HFS), (p < 0.001) and the correlation was r = 0.90. No significant difference was detected in the mean fat mass (kg) between DXA and HFS results, (p = 0.08). Figure 1 (A) depicts the Bland Altman plot of body fat

Table I
Mean of the body fat percentage, body fat mass and fat free mass index obtained by DXA, hand to foot and foot to foot BIA analyzers

	DXA		BIA Hand to foot		P*	BIA Foot to foot		P*
	Mean	(SD)	Mean	(SD)		Mean	(SD)	
Fat mass (%)	35.36	(7.0)	34.40	(6.0)	0.0001	28.66	(6.7)	0.0001
Fat mass (kg)	20.30	(8.6)	21.00	(8.8)	0.0800	17.30	(7.5)	0.0001
Fat free mass index (kg/m ²)	14.18	(1.5)	14.95	(1.4)	0.0001	16.29	(1.5)	0.0001

¹SD: Standar Deviation. *P value between DXA and BIA analyzers using paired Student' t- test.

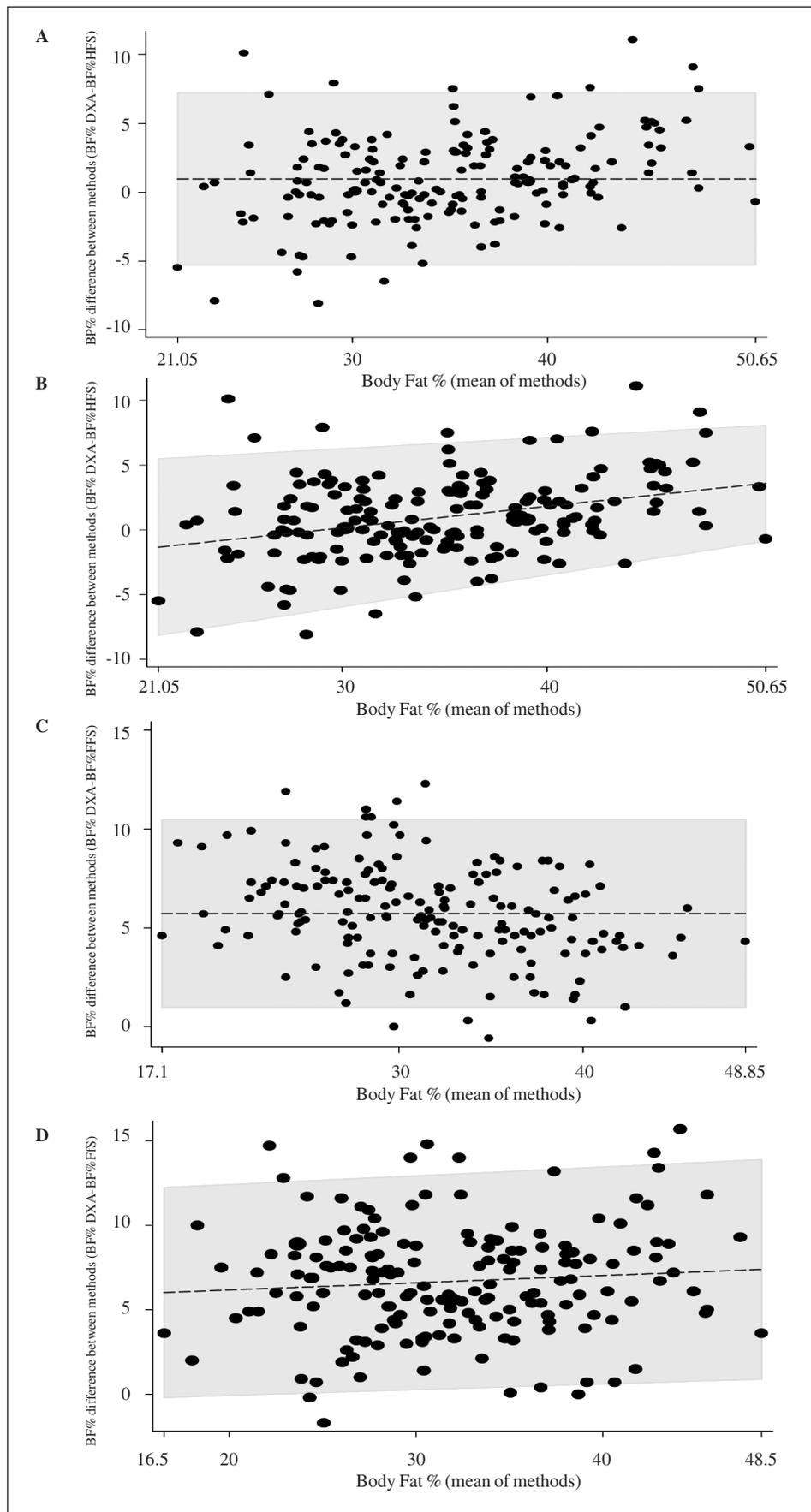


Fig. 1.—(A) Bland Altman plot of Body Fat percentage (BF%) with mean difference (-0.96) and 95% limits of agreement (-5.29, 7.21) between DXA and BIA Hand-Foot system (HFS). (B) Linear relationship between the paired BF% difference and paired BF% average of DXA and HFS, and 95% limits of agreement. The positive slope indicates that the difference between methods was larger with higher BF% values (mean difference = $-4.85 + 0.17 \times \text{mean BF\%}$). (C) Bland Altman plot of BF% with mean difference (-6.69) and 95% limits of agreement (-0.29, -13.09) between DXA and FFS. (D) Linear relationship between the paired Body Fat percentage (BF%) difference and paired body fat percentage and average of DXA and FFS, and 95% limits of agreement. The positive slope indicates that the difference between methods was larger with higher BF% values (mean difference = $5.32 + 0.04 \times \text{mean BF\%}$).

percentage (BF%) between DXA and BIA HFS, with a mean difference of -0.96 and 95% limits of agreement (CL -5.29, 7.21). Figure 1 (B) presents the regression line between the paired difference and the paired mean of body fat percentage (BF%) between DXA and BIA HSF 6.9% of the measurements were outside the limits of agreement.

The matched paired comparison of BF% between DXA and BIA-FFS showed a significant difference of -6.69 (35.36% DXA vs 28.66% BIA FFS), ($p < 0.001$), and the $r = 0.89$. Figure 1 (C) presents the Bland Altman plot between DXA BF% and BIA FFS BF%; the mean difference close to -6.69% indicated an underestimation of the BIA-FFS equipment in this percentage and wide limits of agreement (CL -0.29, -13.09). Figure 1 (D) presents the regression line obtained be-

tween the paired difference and the paired mean of body fat percentage (BF%) between the DXA and BIA FFS 6.7% of the measurements were outside the limits of agreement.

The comparison of BF% of the two BIA systems studied showed a significant difference (34.40% vs 28.66% BIA FFS), ($p < 0.001$), and the $r = 0.93$. The FFS showed lower values (mean difference = -5.73), (CL -0.94, -10.48), and 5.71% of the observations were outside of the limits of agreement, figure 2 (A). Figure 2 (B) shows the regression line obtained between the paired difference and the paired mean of body fat percentage (BF%) between BIA HFS and 95% limits ($\pm 2.46 * (2.35 + -0.02 * \text{mean})$), and 5.7% of the measurements were outside the limits of agreement.

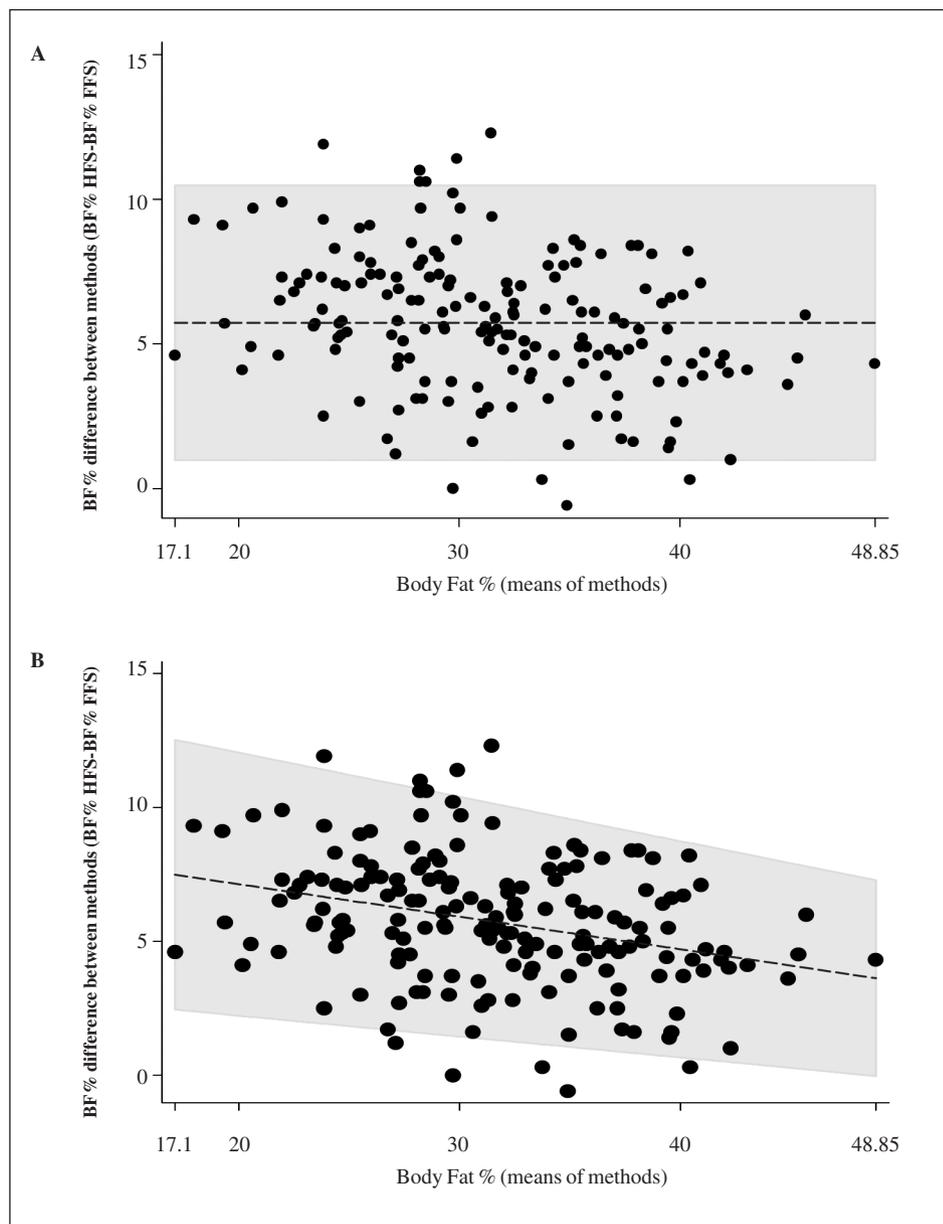


Fig. 2.—(A) Bland Altman plot of Body Fat percentage (BF%) with mean difference (5.73) and 95% limits of agreement (0.97, 10.48) between BIA Hand-Foot system (HFS) and BIA Foot-Foot system (FFS). (B) Linear relationship between the paired BF% difference and paired BF% average of HFS and FFS, and 95% limits of agreement. The negative slope indicates that the difference between methods were lower as BF% increased (mean difference = $9.56 + -0.12 * \text{mean BF%}$).

Fat Free Mass Index

The matched pair difference between DXA and BIA HFS was statistically significant ($14.18 \text{ kg/m}^2 \text{ DXA vs } 14.95 \text{ kg/m}^2 \text{ BIA HFS}$), ($p < 0.001$), (table I); however, this difference was small (mean difference = 0.78), and the correlation was $r = 0.85$. Figure 3 (A) presents the Bland Altman plot of the FFMI comparing the DXA

and BIA HFS results; the limits of agreement were between $(-2.27, 0.72)$, and 5.7% of the observations were outside of the limits of agreement.

The mean difference between DXA and BIA FFS showed a significant difference ($14.18 \text{ kg/m}^2 \text{ DXA vs } 16.29 \text{ kg/m}^2 \text{ BIA FFS}$), ($p < 0.0001$); higher values were obtained using the BIA FFS (mean difference = 2.11) than with DXA; and the correlation was $r = 0.83$.

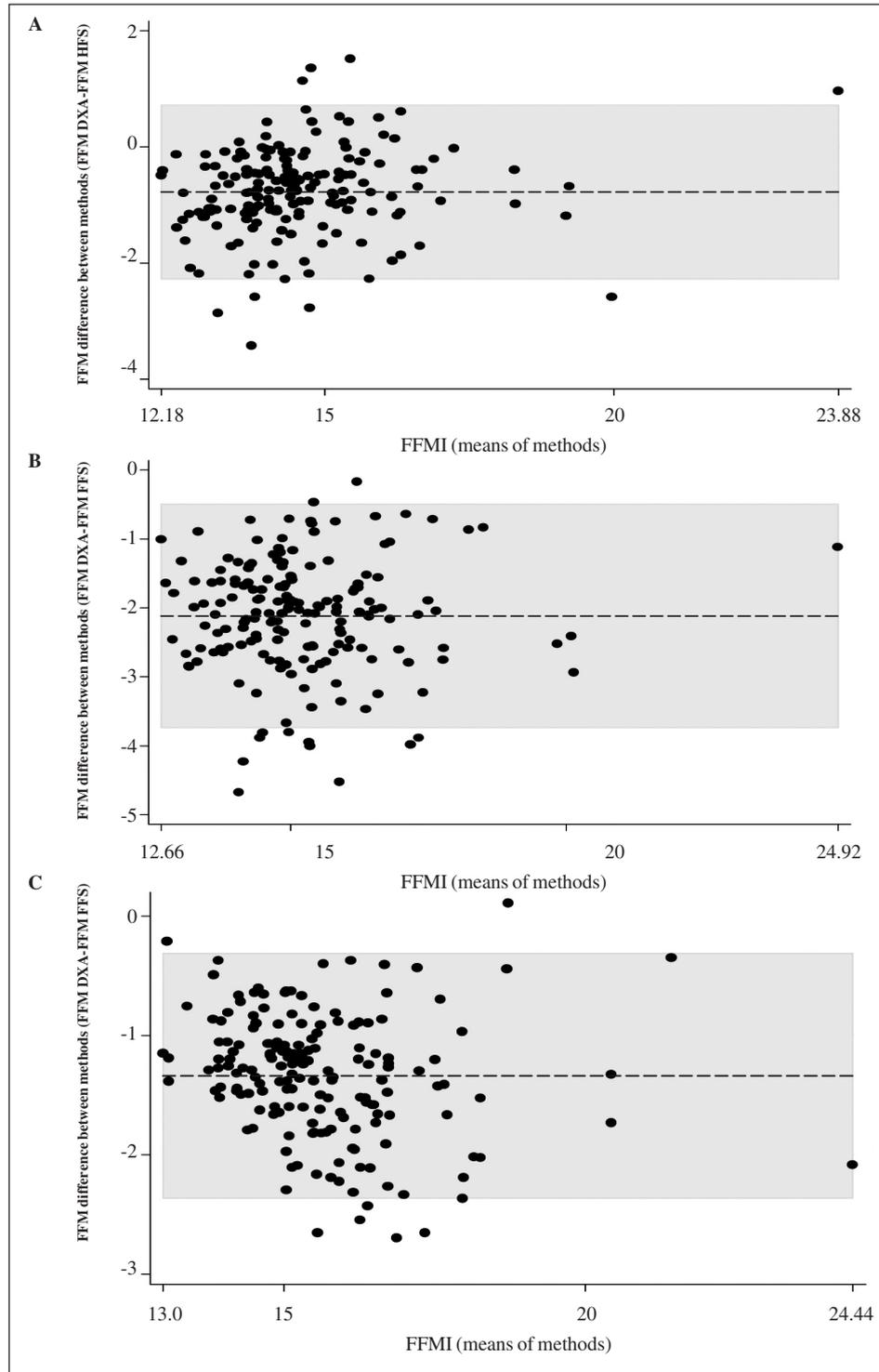


Fig. 3.—(A) Bland Altman plot of Fat Free Mass index (FFMI (kg/m^2)) with mean difference (-0.78) and 95% limits of agreement ($-2.27, 0.72$) between DXA (FFMI DXA) and BIA Hand-Foot system (FFMI HFS), (B) Bland Altman plot of FFMI with mean difference (-2.12) and 95% limits of agreement ($-3.74, -0.49$) between DXA (FFMI DXA) and BIA Foot-Foot system (FFMI DXA), (C) Bland Altman plot of Fat Free Mass index (FFMI (kg/m^2)) with mean difference (-1.33) and 95% limits of agreement ($-2.36, -0.31$) between BIA Hand-Foot system (HFMI FFS) and BIA Foot-Foot system (FFMI FFS).

Figure 3 (B) presents the Bland and Altman plot of the FFMI comparing the DXA and BIA FFS results. The limits of agreement were between (-3.73,-0.49), and 6.86% of the observations were outside of the limits of agreement. Figure 3 (C) depicts the Bland Altman plot of the two BIA systems. The mean difference was 1.33, and the 95% limits of agreement were (0.31, 2.36). The matched pair difference was significant (14.95 kg/m² BIA HFS vs 16.29 kg/m² BIA FFS), ($p < 0.001$). The percentage of observations outside the limits of agreement was 4.57%. The correlation was 0.90.

Discussion

In the present study, we assessed the validity of two types of BIA (HFS and FFS) systems. We compared the estimates of body fat percentage and fat-free mass index with DXA results as the reference method. The HFS and the FFS equipment showed biases of different magnitude.

Body fat percentage

The values of body fat percentage obtained by BIA HFS equipment and DXA were close to each other. We found significant statistical differences in the paired comparisons. However, the mean difference between DXA vs. HFS was approximately one percentage point; clinically, this difference is small, although significant in statistical analysis.

However, the limits of agreement between DXA and HFS were wide; therefore, the bias could be large and the methods cannot be considered equivalent for a given patient. The limits of agreement showed a higher bias as the BF% increased; this bias was slightly different at diverse levels of BF%; and the limits tended to be narrower at higher values of BF%. Similar data were reported in a group of adult women aged 18-39 years²².

DXA discrepancies vs. BIA probably are due to various factors, such as the characteristics of the equipment used, equations applied, electrical frequency, and the number of electrodes of each device, as well as the hydration status of the participants. The results can be affected by fluid retention or the state of hydration because the BIA technique is based on the conduction of electric current across the body's water by electrolytes, which are good conductors, and the opposition of electrical flow is used to estimate total body water and lean mass, assuming that the lean body mass contains nearly about 73% of water²³.

In this study, we found that body fat could be underestimated by 6.7%, comparing FFS with DXA. This is relevant from a clinical point of view, because the patients would be informed of having a lower BF% than they really had. In addition, the regression analysis showed higher variation with higher BF% values.

The underestimation of the FFS BIA could be attributed to a technique that is doubly indirect in relation to DXA, which is an indirect technique based on two X-ray beams with different energy levels. BIA systems have several advantages for the assessment of body composition in clinical settings: the equipment is portable and less expensive than DXA, easy and simple to use, and quick; but it needs to be used with caution, especially for the assessment of patients who are overweight or obese²⁴. When using bioelectrical impedance analysis, clinicians should consider various factors such as their biophysical principles, methodological foundations, previous validation studies in the population (according to ethnic origin), measurement conditions, and intra- and inter-individual variability. In addition, it is important to consider other factors associated with the characteristics of the study population: obesity, weight loss, menstrual cycle, racial variations, among others²⁵.

The mean difference between the BIA equipment studied (HFS vs FFS) was statistically significant and of clinical importance: the BIA FFS underestimated BF% by almost six percentage points, which in daily medical or nutritional counseling is relevant. The limits of agreement were wide but narrower than those found between DXA and both BIA systems. The results of BF% of the HFS were closer to those of DXA than the results obtained by the FFS studied.

Fat-Free Mass Index

The results of the comparisons of the FFMI agreed with the findings of the BF%: the FFMI results of the HFS device were close to those found by DXA; however, the limits of agreement were wide. The FFS had a larger difference than the HFS results and also showed wide limits of agreement. The results of both BIA systems studied were closer to DXA than the results found regarding the BF%.

The fat-free mass index is not a new concept. VanItallie et al. were the first to define it nearly 20 years ago to overcome some of the limitations related to the simple expressions of FM and FFM in absolute terms²⁶. There are new ranges of standard normality for BMI and recommended percentage of fat²⁷, but this does not mean these constitute a normal or healthy amount of FFM. Just as BMI is a useful tool to compare body weight in individuals who differ in height, the FFMI has proven a useful measurement to compare body composition in subjects who differ in height and content of FFM²⁸. FMI seems to be a better indicator to provide information about body compartments than measurements that do not take height into account.

Body composition results evaluated by HFS BIA were similar to the values obtained by DXA on average. This could suggest that the HFS method used is reliable for evaluating young Mexican women. Body composition measurements obtained by the HFS were closer to the results estimated by DXA than the values

obtained by the FFS equipment used in the present study. The results of the FFS equipment showed a considerable underestimation of BF% and an overestimation of the FFMI. In addition, the limits of agreement were wide in both BIA systems and they showed an increase in bias as in the case of the BF% and FFMI when the values were larger.

Clinicians should be aware of the accuracy of their patients' body composition assessments, that different types of BIA equipment had different levels of bias, and that the results of different BIA systems may not be interchangeable. It is important to consider these aspects in helping their patients achieve healthy weight. Clinicians should pay close attention when interpreting the values of fat mass percentage obtained by BIA in clinical practice, particularly in obese or overweight patients.

Finally, the BMI values of 84.3% of the students were within the normal standard range, which was higher than the national prevalence for women of the same age group (42.1%) according to the results obtained in the Mexican National Health and Nutrition Survey for 2012¹. This may affect the external validity of the study. The low prevalence of the overweight and obese conditions could be due to the fact that the participants were students of human nutrition science, and they were interested in healthy lifestyles.

Similarly, a high prevalence of normal weight was observed in other studies with young women: for example, Ledo Varela et al. in Spain found a prevalence of over 85.0%²⁹, and Vanessa Mealha et al. registered prevalence of over 90.0% in a sample of university students in Portugal³⁰. The mean value of the fat mass percentage was higher in the Mexican students compared with the findings of a similar study published by Albuquerque-Sendin et al. about Spanish young women (35.36% vs 28.1%)³¹ and in another study from Irish women with similar ages (35.36% vs 29.9%)³². The high body fat percentage found in the Mexican women studied is of concern and nutritional counseling is in order.

Limitations of the study

The study group was restricted to Mexican women from 20 to 30 years of age. Most were within a normal range of BMI. The results probably are not valid for other population groups.

Conclusion

Although BIA systems are used in clinical practice, not all BIA equipments are reliable in different population groups. In this study we compared two different tools: a hand-to-foot system and a foot-to-foot system. The HTF appears more reliable than the FTF system to evaluate body fat percentage and fat-free mass index in young Mexican women.

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References

1. Gutierrez JP, Rivera-Dommarco J, Shamah-Levy T, Villalpando-Hernandez S, Franco A, Cuevas-Nasu L, Romero-Martinez M, Hernandez-Avila M. *Encuesta Nacional de Salud y Nutrición 2012. Resultados Nacionales*. Cuernavaca, Mexico: Instituto Nacional de Salud Pública (MX), 2012.
2. Karakas P, Gülhal Bozquir M. Anthropometric indices in relation to overweight and obesity among Turkish medical students. *Arch Med Sci* 2012; 2: 209-13.
3. Sharma AM, Chetty VT. Obesity, hypertension and insulin resistance. *Acta Diabetol* 2005; 42 (Supl. 1): S3-S8.
4. Symonides B, Jedrusik P, Artysuk L, Grybos A, Dzilinski P, Gaciong Z. Different diagnostic criteria significantly affect the rates of hypertension in 18-year-old high school students. *Arch med Sci* 2010; 6: 689-94.
5. Thibault R, Pichard C. The evaluation of body composition: a useful tool for clinical practice. *Ann Nutr Metab* 2012; 60: 6-16.
6. Rubiano F, Nuñez C, Heymsfield SD. A comparison of body composition techniques. *Ann N Y Acad Sci* 2000; 904: 335-8.
7. Kelly TL, Wilson KE, Heymsfield SB. Dual Energy X-Ray Absorptiometry Body Composition Reference Values from NHANES. *PLoS ONE* 2009; 15; 4,9:e70-38.
8. Aaesen G, Fagertum_H & Halse J. Body composition analysis by dual x-ray absorptiometry: *in vivo* and *in vitro* comparison of three different fan beam instruments. *Scand J Clin Lab Invest* 2006; 66: 659-66.
9. Wang Z, Pierson RN Jr. Total body carbon and oxygen masses: evaluation of dual-energy x-ray absorptiometry estimation *in vivo* neutron activation analysis. *Phys Med Biol* 2010; 55: 5953-63.
10. Wang Z, Heymsfield SB, Chen Z, Zhu S, Pierson RN. Estimation of percentage body fat by dual-energy x-ray absorptiometry evaluation *in vivo* human elemental composition. *Phys Med Biol* 2010; 55: 2619-35.
11. Ellis KJ. Human body composition: *in vivo* methods. *Physiol Rev* 2000; 80: 649-80.
12. Chumlea CW and Shumei SS. Bioelectrical impedance analyses. In: Heymsfield SB, Lohman TG, Wang ZM, and Going SB. Chapter 6: 79-88. *Human Body Composition*. 2nd ed, Human Kinetics, Champaign, IL 2005.
13. Lukaski HC, Siders WA. Validity and accuracy of regional bioelectrical impedance devices to determine whole-body fatness. *Nutrition* 2003; 19: 851-7.
14. Bolanowski M, Nilsson BE. Assessment of human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. *Med Sci Monit* 2001; 7: 1029-33.
15. Kitano T, Kitano N, Inomoto T, Futatsuka M. Evaluation of body composition using dual-energy X-ray absorptiometry, skinfold thickness and bioelectrical impedance analysis in Japanese female college students. *J Nutr Sci Vitaminol* 2001; 47: 122-5.
16. Ravaglia G, Forti P, Maioli F, Boschi F, Cicognani A, Gasbarrini G. Measurement of body fat in healthy elderly men: a comparison of methods. *J Gerontol A Biol Sci Med Sci* 1999; 54: 70-6.
17. Erselcan T, Candan F, Saruhan S, Ayca T. Comparison of body composition analysis methods in clinical routine. *Ann Nutr Metab* 2000; 44: 243-8. 29.
18. Wattanapenpaiboon N, Lukito W, Strauss BJ, Hsu-Hage BH, Wahlqvist ML, Stroud DB. Agreement of skinfold measurement and bioelectrical impedance analysis (BIA) methods with dual energy X-ray absorptiometry (DXA) in estimating total body fat in Anglo-Celtic Australians. *Int J Obes Relat Metab Disord* 1998; 22: 854-60.

19. Spencer CE, Lingard JM, Bermingham MA. Comparison of a footpad analyser with a tetrapolar model for the determination of percent body fat in young men. *J Sci Med Sport* 2003; 6: 455-60.
20. Demura S, Sato S, Kitabayashi T. Estimation accuracy of percent total body fat and percent segmental fat measured by single-frequency bioelectrical impedance analysis with 8 electrodes: the effect of difference in adiposity. *J Sports Med Phys Fitness* 2005; 45: 68-76.
21. International Atomic Energy Agency (IAEA) Dual Energy X ray Absorptiometry for bone mineral density and human body assessment. *Human Health Series*. No. 15 Vienna.2010.
22. Leahy S, O'Neill C, Sohun R, Jakeman P. A comparison of dual energy X- ray absorptiometry and bioelectrical impedance analysis to measure total and segmental body composition in healthy young adults. *Eur J Appl Physiol* 2012; 112: 589-95.
23. Wang Z, Deurenberg P, Wang W, Pietrobelli A, Baumgartner RN, Heymsfield SB: Hydration of fat-free body mass: review and critique of a classic body-composition constant. *Am J Clin Nutr* 1999; 69 (5): 833-41.
24. Sato S, Demura S, Kitabayashi T and Noguchi T. Segmental Body Composition Assessment for Obese Japanese Adults by Single-Frequency Bioelectrical Impedance Analysis with 8-point Contact Electrode. *J Physiol Anthropol* 2007; 26 (5): 533-40.
25. Dehghan M, Merchant TA. Is bioelectrical impedance accurate for use in large epidemiological studies? *Nut J* 2008; 7: 26; 1-7.
26. VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA. Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. *Am J Clin Nutr* 1990; 52: 953-59.
27. Gallagher D, Heymsfield SB, Heo M, Jebb SA, Murgatroyd PR, Sakamoto Y. Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. *Am J Clin Nutr* 2000; 72: 694-701.
28. Kyle UG, Schutz Y, Dupertuis YM, Pichard C. Body composition interpretation. Contributions of the fat-free mass index and the body fat mass index. *Nutrition* 2003; 19 (7-8): 597-604.
29. Ledo Varela MT, De Luis Román DA, González Sagrado M, Izaola Jauregui O, Conde Vicente RY, Aller de la Fuente R. Características nutricionales y estilos de vida en universitarios. *Nutr Hosp* 2011; 26: 814-8.
30. Mealha V, Ferreira C, Guerra I, Ravasco P. Students of dietetics & nutrition; a high risk for eating disorders? *Nutr Hosp* 2013; 28: 1558-66.
31. Alburquerque-Sendín F, Martín-Vallejo FJ, García-Talavera P, Martín Gómez ME, and Santos del Rey M. Comparison of fat mass and fat-free mass between Anthropometry, BIA and DEXA in young females: are methods interchangeable? *Eur J Anat* 2010; 14: 133-41.
32. Leahy S, O'Neill C, Sohun R, Jakeman P. A comparison of dual energy X-ray absorptiometry and bioelectrical impedance analysis to measure total and segmental body composition in healthy young adults. *Eur J Appl Physiol* 2012; 112: 589-95.