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Comparison of fat mass and fat-free mass between Anthropometry, BIA and DEXA in young females: are methods really interchangeable?

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Summary

The aim of this study was to check the degree of consistency and agreement between three methods for the estimation of body composition, fat mass and fat-free mass after their application to a group of young women. A transverse observation study was performed. Fifty-nine women aged between 18 and 28 years old were included. Each woman was subjected to three assessments of body composition: anthropometry, dual-energy x-ray absorptiometry and bio-impedance analysis. Pearson's r coefficient and the Cronbach α were calculated. To check the degree of agreement, analysis of variance was implemented for repeated measurements and Bland and Altman plot was used. Differences were observed among the four assessment methodologies, the results of the General Durnin & Womersley Formula departing from those of the others, such that it was left out. In contrast, the consistency of the Specific Durnin & Womersley Formula was better in fat mass. Regarding the level of agreement between pairs of methods, a homogenous pattern was observed, with low bias, although broad 95% agreement limits were observed. These results indicate that different methods of body composition assessment provide different estimations in a sample of healthy young women. Dual-energy x-ray absorptiometry and anthropometry (Specific Durnin & Womersley Formula) have high levels of consistency, with low bias ranges.

Key words: Body composition – Bioelectric impedance – X-ray densitometry – Anthropometry – Levels of agreement

Introduction

The measurement of body composition (BC) affords information used by nutritionists, clinicians and physiologists to understand processes such as ageing, obesity, and pathologies that course with constitutional changes such as obesity, cancer or AIDS (Laskey, 1996; Pineau et al., 2007; Rezende et al., 2007).

Dual-energy X-ray absorptiometry (DEXA) is the technique most widely employed to measure bone density (Kerr et al., 2007) with clinical applications (Albanese et al., 2003). Multiple-component models have shown that DEXA results are strongly related to BC (Salamone et al., 2000; Schoeller et al., 2005). However, there are variations in the methods

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used, in the generation of different rays, the type of DEXA device, and the instrumentation of computing programs and in the characteristics of the sample (Tylavsky et al., 2003; Hull et al., 2009; Sakai et al., 2006; Nakata et al., 2004; Genton et al., 2002), even when developed by the same manufacturer (Wang et al., 2005), such that use of DEXA as a gold standard has been questioned (Roubenoff et al., 1993; Fogli, 2005).

Bioelectrical Impedance Analysis (BIA) is a simple, inexpensive and precise method that can be applied to stable patients and healthy subjects and is well correlated with anthropometric parameters (Casanova et al., 2004; Erselcan et al., 2000). Other studies have also validated BIA for classifying individuals as obese, with a good correlation with the DEXA results (Pietrobelli et al., 2004; Fakhrawi et al., 2009). One of the errors in this method lies in the assumption that the density of Fat mass (FM) is constant. Such equations describe the statistical relationships observed in a given population and each equation is useful for subjects who have characteristics similar to those of the reference population employed in the formulation of each equation (Mast et al., 2002; Sun et al., 2003).

In light of the low operational costs and the relative simplicity of the assessments, anthropometric measurements can be applied to large series and are able to provide population estimations and data for the analysis of secular changes (Roche et al., 1996), although their application requires suitable training and a particular calibration of the devices used in them (Carlyon et al., 1998; Hewitt et al., 2002). The validity is given by the following parameters: a) Knowledge of exactly what is being quantified or estimated; b) Knowledge of the intrinsic and extrinsic validity of the method and of its precision.

The main aim of the present work was to compare three methods (DEXA, BIA and Anthropometry) in the assessment of FM and FFM in terms of consistency and agreement.

Material and Methods

Design

This was a transverse observational study, in which each individual in the sample was subjected to three consecutive assessments of BC. The analyst was blind to the data.

Subjects

The participants were students of the Nursing and Physiotherapy School of the University of Salamanca (Spain) and were all Caucasian. They were recruited through informative group interviews. The total number of participants was 80, although the final sample was reduced to 59, and their ages were between 18 and 28. The loss of participants from the initial sample was due to their not appearing on the day of the tests or only doing some of them owing to the impossibility of following the assessment protocol. *Exclusion criteria*: a) subjects unable to adopt the static position for the 7 minutes the DEXA exploration lasted; b) the presence of prostheses and/or metal implants; c) having received high doses of radiation previously; d) abundant ingestion of water, alcohol or food prior to the analysis (at least 2 hours); e) physical exercise before the analysis (4 hours); f) the impossibility of evacuating the bladder before undergoing BIA; g) the presence of a pacemaker, previous studies with nuclear medicine, etc: h) ingestion of drugs which could change the BC; i) pathologies that could alter or affect the estimation of BC (metabolic, endocrine disorders, kidney disease, cardiac insufficiency, etc); j) pre-menstrual syndrome (owing to the possible retention of fluids), the possibility of pregnancy, and lactation. Ethical approval for the study was granted by the Ethical Committee of the University of Salamanca (USAL, 68/2007). All participants signed the informed consent and all procedures were conducted according to the Declaration of Helsinki.

Assessment protocol

All measurements were made under similar conditions of temperature (20-22º C) and schedule (09:00-12:00). The anthropometric measurements were analysed with a measurement error within internationally accepted ranges (intra-class technical error of less than 5% for skinfolds and of 2% for the rest of the measurements; inter-class technical error of less than 10% for folds and 2% for the rest of the measurements), following the protocols established for such purposes.

The sequence of exploration was: 1. The subjects went to the appointment at the Nuclear Medicine Unit (University Hospital of Salamanca), where they were measured (height) and weighed, and where they completed a questionnaire in order to apply the inclusion/exclusion criteria. 2. DEXA was performed; 3. The individuals were sent to the Department of Human Anatomy and Histology; 4. For BIA, the individuals were told to go to the appointment with an empty bladder; 5. Anthropometric measurements were taken: skinfolds (bicipital, tricipital, subscapular, supraspinal, abdominal, iliac crest, anterior thigh and medial leg), diameters (femoral bistyloid and bicondyle) and perimeters (minimum abdominal and maximal gluteal).

Measuring devices

A HOLOGIC (Waltham MA QDR4500 densitometer, software 8.1) and a tetrapolar (tarsus-metatarsus/carpal-metacarpal) multifrequence (1-5-10-50-100 KHz, 100-800 Ohms) BodyCell ElectromediCarin S.A bioimpedancemeter (precision of the data was ±2%; mean phase range was 0-20º; maximum measuring current 500 μA, rms) were employed. Anthropometric instrumentation: a digital Soehnle scale, precision 0.1 Kg (evaluated with fitness discs); an ElectromediCarin height meter, precision 0.1mm. A Holtain Ltd. (Crymych, UK) skinfoldmeter: precision 1mm (three sequential consecutive measurements were taken, considering the median or the trend); an anthropometric tape measure from Holtain Ltd, precision 1 mm; a Berfer pachymeter: precision 0.1 mm. As well as the isolated measures, the following were obtained: Body Mass Index (BMI), expressed in Kg/m^2, and waist/hip index (minimum abdominal perimeter/maximum gluteal perimeter, without units). Using the four-compartment model proposed by De Rose and Guimaraes, the total mass was divided up as: FM, bone mass, muscle mass, and residual mass (De Rose and Guimaraes, 1980). Fat-free mass (FFM) was the sum of the non-fatty components (in Kg).

%FM was calculated according to the Specific Durnin & Womersley Formula for this age range (Durnin and Womersley, 1974) - $\%FM_{DurninSpecific}$-: %FM obtained from the Siri formula.

$$\%FM_{DurninSpecific}\,(♀) = (4.95/\,Density_{DurninSpecific}) - 4.5) \times 100$$

where $Density_{DurninSpecific} = 1.1599 - (0.0717 \times Log\,(Triceps\ skinfold + Biceps\ skinfold + Iliac\ crest\ skinfold + Subscapular\ skinfold).$

%FM was calculated according to the General Durnin & Womersley Formula ($\%FM_{DurninGeneral}$) (Durnin and Womersley, 1974): %FM obtained from the Siri formula.

$$\%FM_{DurninGeneral}\,(♀) = ((4.95/\,Density_{DurninGeneral}) - 4.5) \times 100$$

where $Density_{DurninGeneral} = 1.1567 - (0.0717 \times Log(Triceps\ skinfold + Biceps\ skinfold + Iliac\ crest\ skinfold + Subscapular\ skinfold).$

Statistical analyses

Description of the quantitative variables was performed using the mean, standard deviation, maxima and minima. The qualitative variables are described using frequency tables. The normality was checked using the Kolmogorov-Smirnov test.

The methods were compared from two points of view. Since two methods are consistent when the association is strong and also positive according to the correlation test for each pair of methods and for the assessment of the overall consistency of all the models assessed, the standardised Cronbach α was used (Cronbach, 1951). The correlations were performed without transformation into percentages, because this coefficient is sensitive to the range of the variables (Bland and Altman, 2003). The other aspect considered was the degree of agreement shown by the assessment methods. The existence of agreement or concordance between observations is considered when the methods can be interchanged; i.e., the assessments of one of the methods can be considered as correct as those of the other method with which it is being compared (Mantha et al., 2000). Two analyses were employed to explore the agreement among methods: ANOVA of repeated measurements (different assessment methods), and that of Bland-Altman plots (Bland and Altman, 1986).

A p-value less than 0.05 was considered as statistically significant for all analyses. Software: JMP 7.0 and EXCEL®.

Results

The final sample comprised 59 women (19.93±1.88 years). The women in the sample were seen to do little physical exercise, more than half of them (61%) not doing any at all. This variable was categorised in 4 groups as a function of the number of hours spent doing physical exercise (Table 1). The BMI values were within the normal limits for this age sector, but in some cases were lower (18 Kg/cm^2). Both height and weight and the BMI had a normal distribution.

Table 1. Hours of physical exercise/week (n=59).

	Physical exercise (hours/week)	Frequency	Percentage
INACTIVE	0	36	61.0
LOW	2	2	3.4
	3	4	6.8
	4	9	15.3
MODERATE	5	5	8.5
	8	1	1.7
HEIGH	12	2	3.4

The DEXA, anthropometry and BIA data are shown in Table 2, with normal distribution for all the individuals participating in the survey. For %FM, were identified differences between the methods [$F=3510.52$; $GL_1=3$; $GL_2=174$; $p<0.01$]. There were even statistically significant differences between the Durnin & Womersley formulas ($p<0.01$), although their means were similar. Thus, the %FM of the General Formula was higher than that of the Specific Formula (Figure 1). The same was the case of the %FFM [$F=22245.39$; $GL_1=3$; $GL_2=174$; $p<0.01$]. The analysis was therefore continued without the General Durnin & Womersley Formula, because it afforded values higher than the rest of the evaluations, with greater differences with respect to those shown by the Specific Formula, including higher variabilities than the rest, and showed little accuracy and precision when assessing the BC of the population, since it overestimated FM.

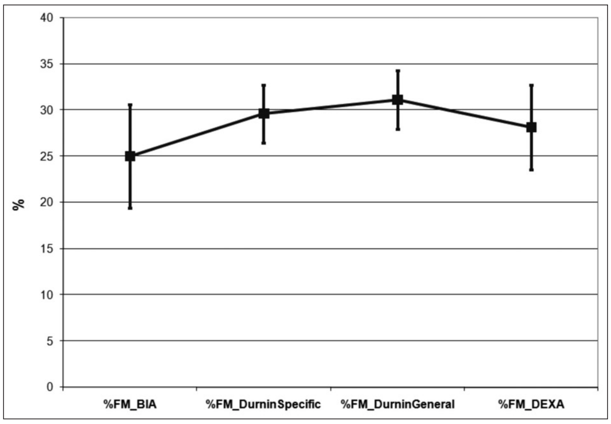

Fig. 1. %FM values according to exploratory methods. Each square point represents the average of %FM obtained with each method. The vertical lines represent the standard deviation of the estimation.

Table 2. Descriptive statistics regarding weight, height and BMI of the sample (n=59).
* Statistically significant difference at the 95% level
** Statistically significant difference at the 99% level

	Variable	Mínimun	Maximun	Mean	S.D.	K-S (p)
General Variables	Height (m)	1.50	1.78	1.63	0.064	0.646 (0.90)
	Weight (Kg)	43.00	77.00	56.41	6.77	0.519 (0.95)
	BMI (Kg/m2)	17.44	24.86	21.04	1.84	0.477 (0.98)
	waist/hip	0.63	0.81	0.72	0.04	0.560 (0.91)
DEXA	FM_DEXA (Kg)	8.77	28.10	16.03	4.02	0.499 (0.96)
	% FM_DEXA	17.43	37.29	28.12	4.61	0.472 (0.98)
	FFM_DEXA (Kg)	32.55	47.94	39.29	3.94	0.643 (0.80)
	% FFM_DEXA	61.48	80.21	69.92	4.37	0.422 (0.99)
BIA	FFM_BIA (Kg)	32.40	50.40	42.07	3.79	0.652 (0.79)
	% FFM_BIA	63.51	88.55	74.99	5.66	0.682 (0.74)
	FM_BIA (Kg)	5.30	28.00	14.33	4.53	0.508 (0.96)
	% FM_BIA	11.45	36.36	24.99	5.61	0.415 (0.99)
ANTHROPOMETRY	FM_DurninGeneral (Kg)	12.07	29.44	17.67	3.59	0.570 (0.90)
	% FM_DurninGeneral	23.55	38.23	31.10	3.16	0.641 (0.81)
	FM_DurninSpecific (Kg)	11.38	28.25	16.82	3.49	0.603 (0.86)
	% FM_DurninSpecific	22.11	36.69	29.61	3.14	0.645 (0.80)
	FFM_DurninGeneral (Kg)	30.63	47.56	38.74	3.85	0.739 (0.65)
	% FFM_DurninGeneral	61.77	76.45	68.90	3.16	0.641 (0.80)
	FFM_DurninSpecific (Kg)	31.27	48.75	39.58	3.95	0.714 (0.69)
	% FFM_DurninSpecific	63.31	77.89	70.39	3.14	0.645 (0.80)

ANOVA analysis between the DEXA, BIA and anthropometric techniques (Specific Durnin & Womersley Formula) revealed statistical differences between the methods [$F=45.491$; $GL_1=2$; $GL_2=112$; $p<0.01$] for the %FM. The BIA results being those that most departed from those of the other two methods (4.62% between BIA and the Specific Durnin & Womersley Formula; 3.13% between BIA and DEXA), while DEXA and the Specific Durnin & Womersley Formula were differentiated by 1.9%.

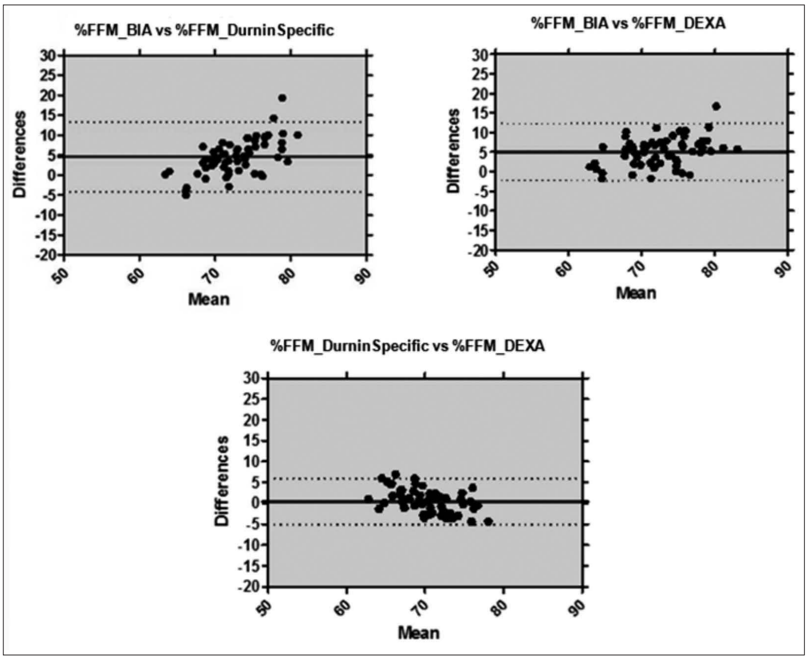

Fig. 2. Bland-Altman plots for the %FFM. Solid line represents the mean difference for the %FFM between pairs of methods; light abbreviated lines represent the 95% confidence interval. Data are presented for the entire sample (n=59).

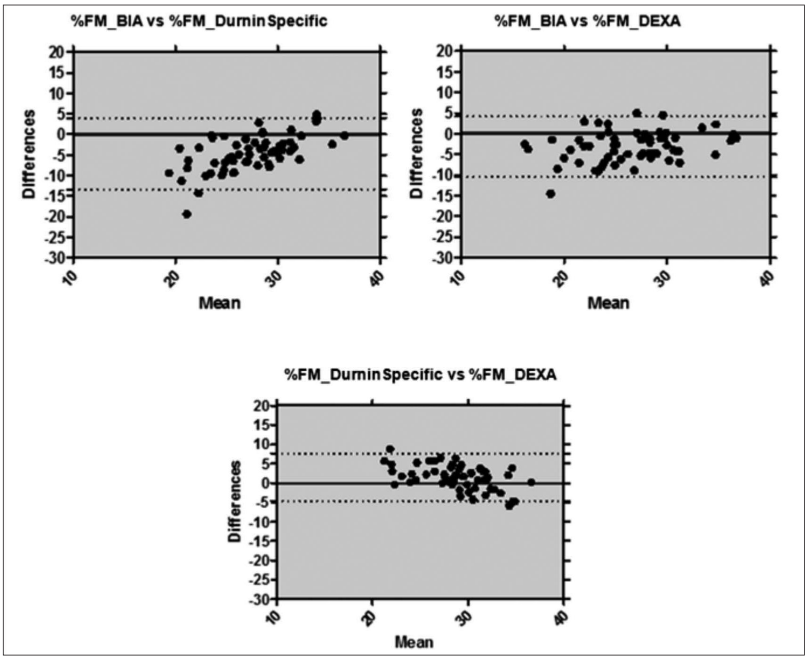

Fig. 3. Bland-Altman plots for the %FM. Solid line represents the mean difference for the %FM between pairs of methods; light abbreviated lines represent the 95% confidence interval. Data are presented for the entire sample (n=59).

Acceptable correlations were obtained. The correlations between DEXA and the other two methods were excellent (r>0.9). The degree of consistency was also high (α=0.963) and always had higher values when DEXA was present (Tables 3 and 4).

Table 3. Correlations among methods for evaluating FM.

	FM_BIA	FM_ Durnin Specific	FM_DXA
FM_BIA	1.0000	0.8744	0.9045
FM_ Durnin Specific	0.8744	1.0000	0.9087
FM_DXA	0.9045	0.9087	1.0000

Table 4. Consistency between pairs of methods for the evaluation of FM.

Method excluded	Cronbach α
FM_BIA	0.9522
FM_ Durnin Specific	0.9499
FM_DXA	0.9330

Regarding the ANOVA performed for the 3 methods for the %FFM, significant differences were observed [$F=66.750$; $GL_1=2$; $GL_2=112$; $p<0.01$]. In the analysis of the methods by pairs, BIA showed significant differences with respect to the other two methods (4.62% between BIA and the Specific Durnin & Womersley Formula, 3.13% between BIA and DEXA), while DEXA and the Specific Durnin & Womersley Formula were differentiated by 1.9%.

On analysing the consistency of the FFM results, fewer differences were found between the results of the methods than with those of FM, with lower correlations, being below 0.9 between BIA and the other two methods. Consistency was excellent (α=0.953). The highest values were found when DEXA was included. The BIA values were the ones that most departed from those of the other two tests as regards consistency while the results of the Specific Durnin & Womersley Formula were close to DEXA (Tables 5 and 6).

Table 5. Correlations between methods for the evaluation of FFM.

	FFM_BIA	FFM_Durnin Specific	FFM_DXA
FFM_BIA	1.0000	0.8168	0.8786
FFM_Durnin Specific	0.8168	1.0000	0.9170
FFM_DXA	0.8786	0.9170	1.0000

Table 6. Consistency between pairs of methods for the evaluation of FM.

Method excluded	Cronbach α
FM_BIA	0.9522
FM_ Durnin Specific	0.9499
FM_DXA	0.9330

For the %FFM, the Bland-Altman plot revealed a bias between DEXA and the Specific Durnin & Womersley Formula (0.47±2.82), with 4% difference with respect to the other two comparisons (BIA-Specific Durnin & Womersley Formula 4.60±4.45; BIA-DEXA 5.07±3.72).

The same happened with the limits of agreement. As may be seen, once again BIA departed from the other two methods in a more marked way (Figure 2).

Regarding the %FM, the levels of agreement were slightly lower than in the %FFM, following the previously observed trend. BIA showed the highest range between limits of agreement (BIA-Specific Durnin & Womersley Formula: 17.31%; BIA-DEXA: 14.61%), while Specific Durnin & Womersley Formula (DEXA was lower, with 12.22%) -Figure 3-.

Discussion

Although the BMI values of the sample were within normal ranges, the investment of the women in physical exercise was scant. This circumstance explains the high %FM in the subjects studied, implying a decrease in their %FFM. Despite this, our sample of women is fairly representative of the Spanish population of similar age (Martín et al., 2001), although it differs to a greater or lesser from other populations (Malinauskas et al., 2006; Pongchaiyakul et al., 2005).

Regarding the body compartment variables, the %FM values recorded with each method differed from those recorded with the other methods. Taking into account the values obtained with the three methods with which the correlations and agreement were finally analysed and those observed when they were analysed pair-wise, the correlations were high (many of them reaching excellent levels: above 0.9). In this sense, the method affording the best results was DEXA, followed by anthropometry (Specific Durnin & Womersley Formula), and finally BIA. By components, the FFM afforded higher correlations than the FM, this latter body compartment proving to be more variable, such that in nearly all the analyses, regardless of the sample size, it had poorer correlations than the FFM as regards both mass and percentages, as has often been reported in the literature (Corcoran et al., 2000; Liu et al., 2005). The agreement between pairs of methods for each individual was not satisfactory, as may be seen in the Bland-Altman dispersion plots. Although the general trend was towards relatively low bias values, the standard deviations of the bias sometimes surpassed 7%. This situation was further exacerbated by the appearance of different and varying ranges between agreement limits. Those lying at around 10% follow the same trend as those reported in the literature. However, even this range, in which 95% of the evaluations are included, affects the exchangeability of the methods, such that a 10% difference between the %FM and the %FFM is still hard to accept. From our point of view, limits of agreement at 95% with biases higher than 3-4% provide little quality to the results, even though the correlations are high (even above 0.8). The errors may lead not only to problems in interpretation but may also hinder investigative work (Sáez, 2004; Erselcan et al., 2000), with relevant epidemiological effects (Guo et al., 2000). These circumstances mean that the methods are not interchangeable either in the adult population (De Lorenzo et al., 2000) or in children (Gutin et al., 1996). In light of the instability of the methods considered to be references, such as

DEXA (Litaker et al., 2003; Johnson et al., 2005), there is no sufficiently valid and stable exploratory model that can be considered a single gold standard. Nevertheless, some authors have suggested that such differences could have clinical repercussions, although this is debatable, depending on the case (Aasen et al., 2006).

Martín et al. (2001) employed several anthropometric formulas to estimate the %FM. All the results, analysed pair-wise, differed ostensibly (with the exception of the %FM obtained with the Specific Durnin & Womersley Formula and its General counterpart), with statistical significance in all cases, and correlations above 0.88, relatively small biases (not greater than 3.7%), and intervals between agreement limits (95%) of between 10 and 15% (with the exception of the pair of formulas of Durnin & Womersley, where the interval was 2.56%) (Martín et al., 2001). In comparison with the results obtained with the Specific Durnin & Womersley Formula, the %FM values (OMROM BF 300) were correlated by 0.88 for its sample of both sexes, with a bias of 1.17 and a range of agreement limits of 14.6, such that these results reveal poorer agreement levels than in our study between BIA and the Specific Durnin & Womersley Formula. Those authors concluded that the results of the Specific Durnin & Womersley Formula can be interchanged with those obtained with BIA, which in light of our own results is perhaps somewhat audacious, despite having been corroborated by other authors (Núñez et al., 1994; Valero et al., 1994; Forte et al., 2005). In this sense, one approach was provided by Deurenberg et al. (2001), who reported that although the predictive equations of the fat component generally afforded good estimations, generalization in the use of formulas was complex. Accordingly, the results of individual studies should be interpreted with caution, as noted by other authors who have studied BIA (Xie et al., 1999; Barrera et al., 1997). In Japanese University students, the same pattern was found: the FM% had correlations of 0.7 and 0.8 for pairs of methods (BIA, DEXA and anthropometry -based on skinfolds-), with slightly higher values for FM, in both cases with statistically significant differences among the methods (Kitano et al., 2001). Ward et al. (2007) used the BioImp 2.4.0 (ImpediMed Ltd.) and DEXA QDR (software 12.4) to evaluate a healthy obese young adult population. In the case of the healthy subjects (men and women), for FM they found high correlations between both methods (r=9.953), with a minimum difference in weight (0.24 Kg) in favour of DEXA, and with no significant differences between the means. However, upon observing their Bland-Altman plot for DEXA and BIA (FFM), the limits of agreement (95%) afford figures of +5 and -12 Kg of weight, such that individual evaluation is not as *good* as might have originally been expected. The low levels of agreement mean that the methods are not interchangeable (Jürimäe et al., 2005).

These results between tests, which can be understood as diagnoses from which clinical decisions can be made, are conflictive. Nevertheless, the population estimations do allow a certain degree of comparability among the methods (with biases of less than 4%), although individual explorations would point to a greater risk of failure.

Finally, it may be affirmed that DEXA and anthropometry (Specific Durnin & Womersley Formula) are the methods with the best agreement. The anthropometric methodology currently continues to be an attractive method for the evaluation of BC (Goodpaster, 2002; Wang et al., 2000).

The limitations to the present study are the use of an exclusively female population; the lack of agreement with the statistical analyses reported in the literature; and the fact that the interpretation of the results does not afford conclusions that can be extrapolated to other populations. Further studies should be carried out in order to improve estimations with respect to the reference standards in all types of population.

Conclusions

The different methods of body composition assessment are not interchangeable in a sample of healthy young women because they provide different estimations of %FM and %FFM. However, DEXA and anthropometry (Specific Durnin & Womersley Formula) have high levels of consistency, with low bias ranges.

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