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Comparison of predicted body fat percentage from anthropometric methods and from impedance in university students

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The objective of the present study was to compare different methods for evaluating body fat percentage (BF%) (anthropometric methods and bioelectrical impedance analysis) in university students. Subjects were 653 healthy students whose mean age, body height, body weight and BMI were 21·1 (SD 2·5) years, 166·0 (SD 8·4) cm, 62·8 (SD 11·0) kg and 22·7 (SD 3·1) kg/m^2, respectively. Results showed that BMI is a poor predictor of body fatness since the sensitivity was low in comparison with the reference method (Siri equation). The lowest values of BF% were obtained using the reference method (Siri equation) (21·8 (SD 6·8) %). The two methods with the highest agreement were Siri and Lean (mean difference, −0·5), followed by Brozek (mean difference, −1·4) and Deurenberg (mean difference, −1·5). The largest mean difference for BF% was between Siri and impedance (−4·5). Although the methods and/or equations used in the present study have been commonly utilised to estimate BF% in young adults, the results must be interpreted with caution in the diagnosis and monitoring of overweight and obesity.

Body fat: Bioelectrical impedance analysis: Anthropometry: University students

Given the rising incidence of obesity in the young population of Western countries and, therefore, the importance of measuring body fat, there has been a resurgence of interest in the evaluation of different body composition methods (Gruber *et al.* 2001; Kitano *et al.* 2001).

The World Health Organization (1995, 1998) defines overweight and obesity at BMI cut-off points of 25 and 30 kg/m^2, respectively, in adult populations. However, there is increasing evidence that these cut-off values are not valid for all populations (Luke *et al.* 1997; Deurenberg *et al.* 1998; Deurenberg-Yap *et al.* 2000) as the relationship between BMI and body fat percentage (BF%) differs between population groups. Furthermore, it is the amount of body fat, rather than the amount of excess weight, that determines the health risks of obesity (World Health Organization, 1998). This explains the increasing interest of scientists and the general public in body fat measurements.

Although there are several methods to estimate BF%, there is no 'gold standard' for both epidemiological studies and personal use. However, some scientific societies such as the Spanish Society for Obesity Research recommend the Siri equation, based on anthropometric measures, to determine BF% (SEEDO, 1996). There are other more accurate methods, for example, the underwater weighing method or dual-energy X-ray absorptiometry, but their cost and complexity limit widespread use (Bray *et al.* 1998).

Comparisons between body composition methods have been made in healthy populations of both children (Ellis, 1996; Gutin *et al.* 1996; Treuth *et al.* 2001; Fors *et al.* 2002) and adults (Heymsfield *et al.* 1990; Wellens *et al.* 1994). Although there is literature on the differences in body composition between university athletes and non-athletic subjects (Emslander *et al.* 1998; Mitsuzono & Komiya, 1991), as far as we know, no study has compared the estimates of BF% by using different methods on university students.

Therefore, the purpose of the present study was to compare estimates of BF% by different methods (anthropometry and bioelectrical impedance analysis) in university students. Additionally, we investigated the association between BF% and BMI to evaluate the screening performance of the BMI focused on individual preventive medicine.

Abbreviations: BF%, body fat percentage; BF%$_{BROZEK}$, body fat percentage predicted by Brozek equation; BF%$_{DEURENBERG}$, body fat percentage predicted by Deurenberg equation; BF%$_{IMP}$, body fat percentage evaluated by impedance; BF%$_{LEAN}$, body fat percentage predicted by Lean equation; BF%$_{SIRI}$, body fat percentage predicted by Siri equation; WHR, waist:hip ratio.

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Methods

Subjects

A cross-sectional study of students from the University of the Basque Country (Spain) was carried out. The sample was composed of 653 individuals (190 males and 463 females) aged 18–30 years and recruited from different degrees. The sample size was considered as representative according to the estimations performed by means of the formula by Martin & De Dios (1993) and according to the deviation of BF% from a previous study in populations of the Basque Community (Servicio Central de Publicaciones del Gobierno Vasco, 1994). A stratified recruitment design was used according to demographic data (age, sex and number of students per campus).

The aim of the present study and the kind of measurements were explained to the participants, who gave their informed written consent. The experimental protocol was approved by the University Ethical Committee on Human Research.

All measurements were done on the same visit at the nutrition and physical anthropology laboratories (University of the Basque Country) and at least 3 h after a meal (including drink). Apart from these measurements, the subjects were requested to refrain from strenuous exercise 12 h before the measurements and they were asked to empty their bladders before the evaluation. Females were not measured during their menstrual period.

Anthropometric measurements

A well-trained anthropometrist performed all the measurements. Body weight was measured to 0·1 kg using a standard beam balance (Añó-Sayol®; Atlántida, Añó Sayol, Barcelona, Spain). Height was measured to the nearest 1 mm using a Harpenden stadiometer (Holtain Ltd, Crymych, Wales, UK). With these data we calculated the BMI (weight (kg)/height (m)^2). The skinfold thicknesses (biceps, triceps, subscapular and supra-iliac) were measured in duplicate on the left side of the body to the nearest 0·1 mm with a Holtain skinfold caliper (Holtain Ltd).

Circumferences of the waist and hip were also taken in duplicate to the nearest 1 mm with a tape measure. BF% was calculated using some prediction equations from the literature: Siri (1961), Brozek (Brozek *et al.* 1963), Deurenberg (Deurenberg *et al.* 1991) and Lean (Lean *et al.* 1996) equations ($BF\%_{SIRI}$, $BF\%_{BROZEK}$, $BF\%_{DEURENBERG}$ and $BF\%_{LEAN}$ respectively). In the Siri and Brozek equations, density was predicted using Durnin & Womersley's formula (Durnin & Womersley, 1974).

The subjects were classified according to BF% using the criteria of Bray *et al.* (1998) for the classification of obesity. BMI was classified according to the categories of obesity and overweight of the World Health Organization (1998). Additionally, we evaluated the regional adiposity using the waist:hip ratio (WHR) and the waist circumference. The volunteers were classified at risk according to Heymsfield *et al.* (1998) and National Institutes of Health criteria (National Institutes of Health, National Heart, Lung and Blood Institute, 1999), respectively. The descriptive statistics of the anthropometric traits and the age of the subjects are displayed in Table 1.

Bioelectrical impedance analysis

Bioelectrical impedance analysis measurements were performed using a tetrapolar multi-frequency impedanciometer (MediSystem-SanoCare Human Systems S.L., Madrid, Spain). All measurements were performed in accordance with the manufacturer's instruction manual. BF% evaluated by impedance ($BF\%_{IMP}$) was estimated using Lohman's formula (Lohman, 1992) based on pre-entered personal particulars (weight, height, age and sex) and impedance value.

Statistical analysis

Data were gathered using SPSS 10.0 (SPSS Inc., Chicago, IL, USA) with significance set at $P<0{\cdot}05$ and presented as mean values and standard deviations. Bland–Altman analysis (Bland & Altman, 1986) was used to test for bias (mean difference) and limits of agreement among all the methods. Measures of BF% from the Siri equation were used as the reference method, according to the recommendation of the Spanish Society for Obesity Research (SEEDO, 1996). Sensitivity, specificity and predictive values were calculated to evaluate the classification of obesity using the BMI as compared with the reference method. In the present study, test sensitivity was the proportion of obesity cases, as diagnosed by the reference method, found by BMI. Specificity refers to the proportion of subjects identified by the reference method as non-obese and that BMI classified correctly. The positive predictive value is the probability that a student classified as obese by BMI actually is found to be so by the reference method. The negative predictive value gives us the probability that a subject classified as non-obese by BMI is also defined as non-obese by the reference method.

Results

Subjects' characteristics

In total, 653 subjects participated in the present study, the 463 females ranging in age from 18 to 30 years, in BMI from 16·7 to 34·2 kg/m^2 and in $BF\%_{SIRI}$ from 12 to 41 %. The 190 males ranged in age from 18 to 29 years, in BMI from 17·5 to 38·6 kg/m^2 and in $BF\%_{SIRI}$ from 7 to 31 %. The characteristics of the subjects are given in Table 1. An acceptable BMI existed for 75·7 % of the subjects and 3·8 % of the total sample were classified as low weight (one male and twenty-four females). Significant differences between the sexes were found for all parameters ($P<0{\cdot}01$), except for subscapular skinfold.

According to $BF\%_{SIRI}$, 6·1 % of the subjects were classified as obese (seven males and thirty-three females) and 9·7 % as overweight (twenty-four males and thirty-nine females). However, according to the BMI classification, 2·5 % were obese (eight males and eight females) and 17·2 % of the total sample were overweight (forty-five males and sixty-seven females).

The results showed the strongest specificity (1) and positive prediction (1) of BMI in the identification of obese subjects (BMI $\geq 30{\cdot}0$ kg/m^2). However, the sensitivity was low (0·4) and negative predictive value was 0·96.

Table 1. Anthropometric data
(Mean values and standard deviations)

	Total (*n* 653)		Males (*n* 190)		Females (*n* 463)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	21·1	2·5	21·2	2·3	21·0	2·6
Weight (kg)	62·8	11·0	73·1	9·9	58·6	8·4
Height (cm)	166·0	8·4	175·2	6·8	162·3	5·8
BMI (kg/m^2)	22·7	3·1	23·9	3·0	22·2	3·0
Waist circumference (cm)	80·5	7·7	83·4	8·0	79·4	7·2
Hip circumference (cm)	94·5	6·9	95·7	6·8	94·1	6·9
WHR	0·9	0·1	0·9	0·1	0·8	0·1
Skinfolds (mm)						
Triceps	16·6	6·3	11·0	5·1	18·9	5·3
Biceps	9·6	4·5	7·0	3·7	10·7	4·4
Subscapular	14·0	5·6	13·5	5·7	14·2	5·6
Supra-iliac	16·3	7·6	14·8	7·6	16·9	7·5
Total of four skinfolds (mm)	56·5	20·8	46·4	19·7	60·6	19·8

WHR, waist:hip ratio.

In the total sample, 3·7 % of the subjects would be falsely classified as non-obese with BMI.

According to the waist circumference, 9·8 % of the total were classified as at risk (3·7 % of the males and 12·3 % of the females). Additionally, according to the WHR, 31·2 % of the total sample were classified as at risk (2·1 % of the males and 43·2 % of the females).

Comparisons of the body fat assessment methods

For the overall female population BF%$_{BROZEK}$ (26·2 (SD 4·2)), BF%$_{DEURENBERG}$ (26·0 (SD 3·3)), BF%$_{LEAN}$ (25·2 (SD 4·0)) and BF%$_{IMP}$ (29·0 (SD 4·1)) were significantly different from BF%$_{SIRI}$ (24·3 (SD 5·8)) ($P<0·001$). For the overall male population BF%$_{BROZEK}$ (16·1 (SD 4·4)), BF%$_{DEURENBERG}$ (16·7 (SD 3·6)) and BF%$_{IMP}$ (20·0 (SD 5·3)) were significantly different from BF%$_{SIRI}$ (15·9 (SD 5·0)) ($P<0·01$).

The lowest values of BF% were obtained with Siri (21·8 (SD 6·8) %), followed by Lean (22·3 (SD 6·2) %), Brozek (23·3 (SD 6·3) %) and Deurenberg (23·3 (SD 5·4) %), with impedance giving the highest value of percentage fat (26·4 (SD 6·1) %). The percentage fat mass from the Lean and Deurenberg equations suggested that 6·9 and 10·0 % were overweight or obese, respectively. BF% from the Brozek equation and from impedance indicated a high tendency towards overweight or obesity (15·6 and 36·5 %, respectively).

When obesity was defined using the BF%$_{SIRI}$ in males, Deurenberg and Brozek equations underestimated BF% at higher values of body fat (BF% $\geq$25) (BF%$_{SIRI}$, 28·1 (SD 2·6); BF%$_{DEURENBERG}$, 25·6 (SD 4·3); BF%$_{BROZEK}$, 26·6 (SD 2·2)) (in all cases, $P<0·05$). In males, the Lean, Deurenberg and Brozek formulas underestimated BF% at higher values of body fat (BF% $\geq$33) (BF%$_{SIRI}$, 35·4 (SD 2·1); BF%$_{LEAN}$, 30·3 (SD 3·9); BF%$_{DEURENBERG}$, 31·7 (SD 3·2); BF%$_{BROZEK}$, 34·0 (SD 1·7)) (in all cases, $P<0·001$).

Limits of agreement

The biases (mean differences) for BF% and the limits of agreement between the five methods are shown in Table 2. For BF%, the two methods with the highest agreement were Siri and Lean, the mean difference being

Table 2. Assessment of agreement between the Siri (1961) equation and the other methods used to estimate body fat percentage

Comparison	Mean difference*	95 % CI	SD*†	CI*	Limits of agreement* Lower	Limits of agreement* Upper
Siri–Brozek‡	−1·4	−1·7, −1·2	2·9	11·4	−7·2	4·3
Siri–Deurenberg§	−1·5	−1·8, −1·2	4·2	16·8	−9·9	6·9
Siri–Lean¶	−0·5	−0·9, −0·1	4·8	19·3	−10·2	9·1
Siri–IMP	−4·5	−4·8, −4·1	4·3	17·2	−13·1	4·2

IMP, impedance analysis.
* Bland–Altman method.
† SD of difference.
‡ Brozek *et al.* (1963).
§ Deurenberg *et al.* (1991).
¶ Lean *et al.* (1996).

−0·5 (95 % CI −0·9, −0·1). However, the largest mean difference for BF% was between Siri and impedance (−4·5). The Bland–Altman plots for BF% illustrate the mean differences and the fairly large limits of agreement by different methods (Fig. 1).

Discussion

Despite a relatively low mean BMI (22·7 (SD 3·1) kg/m^2), body fat levels determined by the Siri equation were classified in 6·1 % of the subjects as obese and in 9·7 % as overweight. The percentages classified as overweight and obese were lower than those reported in previous studies (Lowry *et al.* 2000; Huang *et al.* 2003).

The results showed that the BMI is a poor predictor of body fatness, since the sensitivity was low in comparison with the reference method (Siri equation). It was shown in earlier studies (Garn *et al.* 1986; Smalley *et al.* 1990; Hannan *et al.* 1995; Deurenberg *et al.* 2001) that BMI has considerable limitations in predicting an individual's BF%. This is why the body composition measurement is necessary for the individual evaluation of fatness focused on preventive medicine.

In females, 5·6 % would be falsely classified as non-obese according to their BMI and in males 1·1 % would be falsely classified as obese using this weight–height index. Underprediction of obesity might be considered as a greater error than an equal-magnitude overprediction would be. Classifying an individual as lean, when in fact the individual is truly obese regarding his or her body fatness, may put this individual at risk from diseases associated with obesity and, potentially, delay any possible beneficial therapy.

The different forms of obesity (android and gynoid) and the different health risks associated with them are other considerations to take into account. Recent studies indicate that abdominal obesity is more strongly associated with obesity-related health problems than is adiposity measured by BMI (Booth *et al.* 2000). In the present study, 9·8 and 31·2 % of the students were classified at risk according to the waist circumference and WHR, respectively. We have observed similar results with the Siri equation, waist circumference and WHR. Concerning these results,

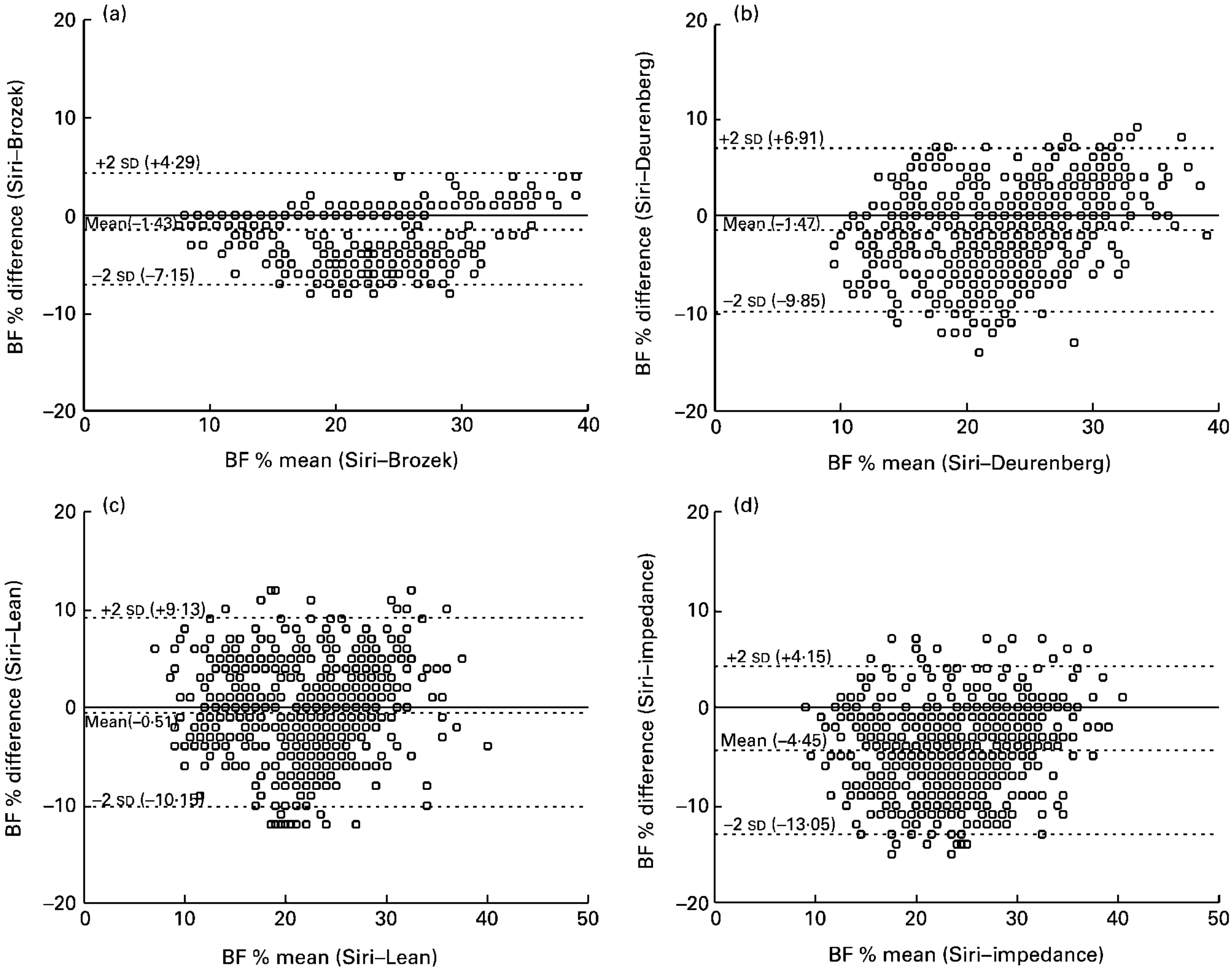

Fig. 1. Bland–Altman plots to compare body fat percentage (BF%) measured by different methods. (a) Comparison of Siri (1961) and Brozek *et al.* (1963) (Siri–Brozek); (b) comparison of Siri (1961) and Deurenberg *et al.* (1991) (Siri–Deurenberg); (c) comparison of Siri (1961) and Lean *et al.* (1996) (Siri–Lean); (d) comparison of Siri (1961) and bioelectrical impedance analysis (Siri–impedance).

Taylor *et al.* (1998) observed that waist circumference was better than the WHR when screening for regional fat distribution using dual-energy X-ray absorptiometry as the reference.

All methods were significantly different for BF%. When considering the bias among methods for BF%, the Siri and Lean equations were the most similar. Not surprisingly, the equation that included the waist circumference (one of the most labile sites of fat deposition) displayed the highest agreement with Siri. However, this situation is somewhat confusing since we registered the highest CI when we compared Siri and Lean. Brozek had the narrowest limits of agreement relative to the reference (−7·2, 4·3 %) of the BF%. It should be noted that Siri and Brozek are the two equations that include log Σ 4 skinfolds. Measurements of skinfold thickness are an easy method of assessing BF% and believed to be reasonably precise (Hannan *et al.* 1995; Sarria *et al.* 1998).

If an error of 4 percentage points BF% is considered as reasonable (Lohman, 1992), in line with the standard error of estimation of most prediction equations (Durnin & Womersley, 1974; Deurenberg *et al.* 1991; Gallagher *et al.* 1996), the present results of mean differences between Siri and impedance are acceptable. However, the CI between Siri and impedance was larger. This is to be expected as the impedance formula uses additional information, which, theoretically, enables us to distinguish between fat and fat-free mass. Bioimpedance analysis would overestimate BF%, so should be used with caution in the diagnosis of obesity in this population.

Different findings have been observed by McNeill *et al.* (1991) in adults and by Deurenberg *et al.* (1989) in children. McNeill *et al.* (1991) observed the skinfold thickness method to be as good as bioelectrical impedance in lean and overweight groups of women. In children, Deurenberg *et al.* (1989) published a study in which prediction formulas for body composition from body impedance were presented; in pre-pubescent boys and girls BF% could be predicted with an error of about 4·2 %, which is comparable with the prediction error for the assessment of BF% from skinfold thickness (Deurenberg *et al.* 1990).

The prediction of BF% from BMI, age and sex (Deurenberg equation) assumes that, when BMI increases over a certain threshold, the excess value is due to body fat in a fixed part. This assumption certainly has its flaws and it explains why the prediction formula generally underestimates BF% at high values of body fat.

Nevertheless, the four methods were different from the Siri equation and, in many cases, the limits of agreement may be considered as high. Similar findings have been observed in children (Parker *et al.* 2003) and in older adults (Aghdassi *et al.* 2001; Barbosa *et al.* 2001). We found that measurements of body fat may depend on many factors, and the different methods studied are generally not directly interchangeable.

Although the methods and/or equations used in the present study have commonly been used to estimate BF% in young adults, they must not be used as a standard method. Each method has limitations and the comparison can be useful for an interpretation of results. More comparative studies should be conducted to get a better insight into the generalisation of prediction methods and formulas. Individual results and classifications have to be interpreted with caution in the diagnosis and monitoring of overweight and obesity.

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