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Agreement of skinfold measurement and bioelectrical impedance analysis (BIA) methods with dual energy X-ray absorptiometry (DEXA) in estimating total body fat in Anglo-Celtic Australians

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OBJECTIVE: To compare percentage total body fat (%BF) estimated by the four skinfold thickness measurement (SKF) and single-frequency bioelectrical impedance analysis (BIA) methods using three different sets of equations, to that assessed by the dual energy X-ray absorptiometric (DEXA) method using a Lunar DPX densitometer.
DESIGN: Cross-sectional study.
SUBJECTS: An Anglo-Celtic Australian population of 66 males and 130 females (age: 26–86 y).
MEASUREMENTS: %BF by anthropometry, BIA using three different sets of equations and DEXA.
RESULTS: Mean %BF assessed by DEXA (%BF_{DEXA}) was similar to that estimated by SKF (%BF_{SKF}) in males, while %BF_{DEXA} was slightly higher in females. %BF estimated by BIA (%BF_{BIA}) was significantly lower than %BF_{DEXA} in females, regardless of equations used for calculation, while the level of agreement between BIA and DEXA in estimating %BF in males was dependent on prediction equations used for calculation of %BF_{BIA}. A better agreement was obtained from the use on the prediction equations of Segal *et al* (1988), compared to other two sets of equations. The agreement between SKF or BIA and DEXA declined with increasing %BF.
CONCLUSIONS: There was a good agreement between DEXA and SKF, and slightly less so between DEXA and BIA, in estimating %BF in an Anglo-Celtic adult population. The agreement in most cases, however, was dependent on the degree of body fatness. In comparison to DEXA, both SKF and BIA, with the use of the equations of Segal *et al* (1988), are applicable to estimate %BF in an Anglo-Celtic Australian population.

Keywords: body fatness; body composition; skinfold thickness; bioelectrical impedance analysis (BIA); dual energy X-ray absorptiometry (DEXA)

Introduction

The major practical methods used to estimate body fat and fat-free mass, since underwater weighing is often unavailable and requires a high degree of cooperation, are the methods based on the sum of four skinfold thicknesses according to Durnin and Womersley[1] (SKF), and bioelectrical impedance analysis (BIA).[2] Dual energy X-ray absorptiometry (DEXA), measures soft tissue body composition, in addition to bone mineral content,[3–5] delivers a low radiation dose and is available at a growing number of locations.

Fat mass and/or fat-free mass comparisons between populations are now appearing.[6,7] However, there are limited data which acknowledge methodological shortcomings or congruence in fat or fat-free mass estimation. Techniques with high accuracy, suitable for use as reference methods, are of value in the research settings, but are not easily applicable to field studies of a large population. It is generally recognised that three principal methods for the estimation of percentage total body fat (%BF), namely DEXA, BIA and SKF, are different not only in the principles of measurements, but also in assumptions required for the calculations. Therefore, there may be differences between %BF values obtained from these methods. The bias or agreement between these methods for estimating %BF has previously been reported, either in healthy subjects or subjects with certain conditions or diseases.[8–13] To our knowledge, there have been three studies conducted in Australia; the first in 12 highly trained male endurance athletes,[12] the second in 14 healthy subjects aged 19–58 y,[5] and the third in 265 subjects aged 4–26 y.[8] The comparison in a relatively larger population of Australian adults (aged≥25y) has not been reported.

Reports of the National Heart Foundation of Australia Risk Factor Prevalence Study, the 1983 National

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Dietary Survey and the 1995 National Nutrition Survey revealed that, from 1983–1995, the prevalence of overweight/obesity (body mass index, BMI$\geq$25 kg/m^2) amongst Australians markedly increased, while the intakes of fat and protein reduced. This evidence indicates that food habits and/or physical activity of Australians, has radically changed, at least in the past 15 years, and could result in a change in the proportion of fat situated subcutaneously and abdominally (body fat distribution). One could raise a question whether the SKF method and the formulae are applicable in estimating %BF in Australians.

The present study evaluated the applicability of SKF and BIA to estimate %BF in an Anglo-Celtic Australian population by assessing agreements between DEXA and SKF, and between DEXA and BIA. In Australia, such people have been in the majority and often serve as a reference point in population health work.

Methods

Study population

A population of 66 males (aged 27–78 y) and 130 females (aged 26–86 y) was studied in the Greater Melbourne Statistical Division. Melbourne is the capital of the Australian State of Victoria, a rather culturally diverse city. Entry criteria included being born in Australia, being of English, Irish, Scottish or Welsh ancestry, apparently healthy, and aged $\geq$25 y. No attempt was made to select on the basis of body habitus, weight change or general health status. Pregnant and lactating females were excluded. Informed consent was obtained from every subject. This study is part of an Anglo-Celtic Nutrition and Health Study approved by the Monash University Standing Committee on Ethics in Research on Humans.

Measurements of %BF

The %BF of each subject was assessed using three different methods, namely by SKF, BIA and DEXA. These assessments wee performed at the Body Composition Laboratory, Clinical Nutrition and Metabolism Unit, Monash Medical Centre. One observer (WL) performed most of the skinfold thickness measurements and BIA, but a small number (<10%) were performed by a second observer, who was well trained to use similar techniques.

SKF method. Measurements of skinfold thicknesses were made to the nearest 0.2 mm, on the right side of the body, at the biceps, triceps, subscapular and suprailiac sites, using a Harpenden caliper (British Indicators Ltd, Luton, UK). Each site was measured in duplicate with the average of the readings being used. The sum of skinfold thicknesses at these four sites was then used to predict body density and %BF (%BF_{SKF}) according to Durnin and Womersley.[1] The calculation of %BF_{SKF} for those older than 72 y (9 males and 16 females) was not made, due to the limitation of the formulae.

BIA method. Subjects were asked to refrain from alcohol and vigorous exercise for 24 h prior to the measurement to minimise perturbation of body fluid. Bioelectrical impedance was measured in a non-fasting state, using a four-terminal impedance plethysmograph (RJL systems, Detroit, MI) according to the instructions of the manufacturer. With minimum clothing, the subject lay supine with arms and legs abducted, and not touching the body. Two current electrodes were placed, one each on the dorsal surfaces of the right hand and right foot, at the distal metacarpals and metatarsals, respectively. Two detector electrodes were placed, one each at the right pisiform prominence of the wrist and between the medial and lateral malleoli of the right ankle. The resistive and reactive components of body impedance were measured to the nearest ohm, in duplicate, without removing the electrodes. Fat free mass (FFM) was estimated by using three different equations. One set of equations was provided with the BIA instrument:

for males,

$$FFM = 6.493 + 0.4936(ht^2/resistance) + 0.332(wt);$$

and for females,

$$FFM = 5.091 + 0.6483(ht^2/resistance) + 0.1699(wt).$$

The other two were generalised regression equations of Lukaski *et al* [14] and Segal *et al*.[15] %BF_{BIA} was then obtained.

DEXA measurement. Body soft tissue composition was determined using a Lunar DPX whole-body X-ray densitometer with Lunar software version 3.6z (Lunar Radiation, Madison, WI). The DPX uses a constant potential X-ray generator at 78 kV and a K-edge filter to produce effective energy levels of 40 keV and 70 keV. In addition to bone mineral content, the analyses provide mass (g), of body fat, lean, sum of total body tissues and %BF_{DEXA}.

Statistical analyses

The statistical procedure of Bland and Altman[16] was used to compare %BF_{SKF} and %BF_{BIA} with %BF_{DEXA} which was used as the criterion method in this study. The limits of agreement between two different methods were defined as, mean $\pm$ 1.96 s.d. of the difference between the methods (95% confidence interval, 95% CI).

Statistical Analysis System software version 6.12 (SAS Institute, Cary, NC) was used for statistical analyses. Mean values of %BF were compared by analysis of variance (ANOVA) for repeated measures, and the correlation of the inter-method difference and mean values was calculated by the Spearman's rank correlation coefficients (r_S).

Results

Comparison of %BF estimated by DEXA with the other two methods

Mean %BF of the study population, estimated by three methods, are listed in Table 1. Results of ANOVA showed that there was a significant difference between $\%BF_{DEXA}$ and $\%BF_{SKF}$ (37.4 *vs* 34.2%, $P < 0.0001$) in females, while no difference was observed in males. Three different sets of prediction equations produced different results of $\%BF_{BIA}$. The values obtained from the manufacturer's equations were significantly lower than $\%BF_{DEXA}$ ($P < 0.0001$) in both males and females. $\%BF_{BIA}$ with the use of either prediction equation from literature was lower than $\%BF_{DEXA}$ in females, but only Segal's equation[15] produced a higher value of $\%BF_{BIA}$ compared to $\%BF_{DEXA}$ in males.

Limits of agreement between DEXA and the other two methods

Table 2 lists the differences between %BF estimated by DEXA and SKF, and by DEXA and BIA, predicted by three different sets of equations. The biases between two methods in obese (BMI≥30 kg/m^2) and non-obese subjects, are also shown in Table 2.

DEXA and SKF. Mean difference of %BF estimated by DEXA and SKF ($\%BF_{DEXA}$ minus %BF) or bias between these two methods was -0.6% (95% CI: -8.5 to 7.3%) in males and 3.0% (-6.0 to 12.0%) in females. It was also observed that there was a positive relationship between the bias and the average of %BF estimated by the two methods ($r_S = 0.44$, $P < 0.0001$), as shown in Figure 1a,b. The positive bias towards DEXA was more apparent in the obese subjects, compared to the non-obese group, especially in females (Table 2).

DEXA and BIA. The bias between DEXA and BIA, using the manufacturer's equations, was 6.8% for males and 8.8% for females. The bias observed in obese subjects was similar to that observed in non-obese subjects (Table 2). BIA, with the use of Lukaski's equations, slightly overestimated %BF in males, but underestimated it in females (Figure 2a,b). Surprisingly, even though a larger bias between DEXA and BIA in estimation off %BF, using the Lukaski's equations,[14] was observed in the obese subjects compared to the non-obese group, no association between the bias and %BF was observed.

Mean bias between DEXA and BIA, using Segal's equations[15] ($\%BF_{DEXA}$ minus $\%BF_{BIA}$) in estimating %BF was -3.6% (95% CI: -11.8 to 4.6%) in males and 2.3% (-5.0 to 9.6%) in females (Figure 3a,b). Similar bias was observed in the non-obese subjects while, interestingly, less bias was observed in the obese subjects (Table 2). An increase in bias between these two methods was associated with increasing %BF ($r_S = 0.56$, $P < 0.0001$).

Discussion

The technique of Bland and Altman,[16] used in the present study to estimate a bias and the limit of agreement for %BF between two measurements, has proved to provide meaningful results and been

Table 1 Characteristics of the study population

	Total		Males		Females	
	n	*Mean ± s.d.*	*n*	*Mean ± s.d.*	*n*	*Mean ± s.d.*
Age (y)	196	56.5 ± 14.1	66	55.9 ± 13.8	130	56.9 ± 14.3
Weight (kg)	196	69.9 ± 11.9	66	78.0 ± 11.1	130	65.8 ± 10.0
Height (cm)	196	165.5 ± 8.7	66	173.8 ± 6.5	130	161.2 ± 6.4
Body mass index (kg/m^2)	196	25.4 ± 3.4	66	25.7 ± 2.9	130	25.3 ± 3.6
Waist-to-hip ratio	194	0.93 ± 0.07	65	0.94 ± 0.05	129	0.92 ± 0.08
Sum of four skinfolds (mm)[a]	196	59.2 ± 19.1	66	51.0 ± 14.4	130	63.4 ± 19.9
Resistance (ohm)	196	537 ± 73	66	482 ± 55	130	565 ± 64
% Total body fat[b]						
DEXA	196	33.1 ± 9.1	66	24.6 ± 5.8	130	37.4 ± 7.2
SKF	171	31.1 ± 6.9*	57	24.7 ± 4.2	114	34.2 ± 5.7***
BIA						
Manufacturer	196	25.0 ± 8.3****	66	17.8 ± 5.2****	130	28.6 ± 7.1****
Lukaski *et al* (1986)	196	30.7 ± 9.4**	66	25.2 ± 8.2	130	33.5 ± 8.7****
Segal *et al* (1988)	196	32.7 ± 6.6	66	28.2 ± 4.8***	130	35.1 ± 6.1**

[a]Sum of (biceps + triceps + subscapular + suprailiac) skinfolds; DEXA = dual energy X-ray absorptiometry; SKF = skinfold thickness measurement; BIA = bioelectrical impedance analysis. Significantly different from DEXA: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; ****$P < 0.0001$ (ANOVA).

Table 2 Mean bias ± 1.96 s.d. for percentage body fat (%BF) estimated by dual energy X-ray absorptiometry (DEXA) and skinfold thickness measurement (SKF), and by DEXA and bioelectrical impedance analysis (BIA)

	Total		*Males*		*Females*	
Bias between methods	*n*	*Mean ± 1.96 s.d.*	*n*	*Mean ± 1.96 s.d.*	*n*	*Mean ± 1.96 s.d.*
Total population						
DEXA − SKF	171	1.8 ± 9.2	57	−0.6 ± 7.9	114	3.0 ± 9.0
DEXA − BIA						
Manufacturer	196	8.1 ± 10.2	66	6.8 ± 10.8	130	8.8 ± 9.6
Lukaski *et al* (1986)	196	2.4 ± 13.0	66	−0.6 ± 14.3	130	3.9 ± 11.3
Segal *et al* (1988)	196	0.3 ± 9.4	66	−3.6 ± 8.2	130	2.3 ± 7.3
Obese subjects[a]						
DEXA − SKF	20	5.2 ± 10.8	7	1.1 ± 10.4	13	7.4 ± 8.8
DEXA − BIA						
Manufacturer	23	8.4 ± 9.4	7	6.0 ± 6.7	16	9.4 ± 9.8
Lukaski *et al* (1986)	23	0.7 ± 12.7	7	−4.9 ± 8.6	16	3.1 ± 11.6
Segal *et al* (1988)	23	1.2 ± 8.8	7	−2.2 ± 5.1	16	2.7 ± 8.6
Non-obese subjects						
DEXA − SKF	151	1.3 ± 8.6	50	−0.8 ± 7.4	101	2.4 ± 8.4
DEXA − BIA						
Manufacturer	173	8.1 ± 10.2	59	7.0 ± 11.2	114	8.7 ± 9.6
Lukaski *et al* (1986)	173	2.6 ± 13.1	59	−0.1 ± 14.7	114	4.0 ± 11.2
Segal *et al* (1988)	173	0.2 ± 9.4	59	−3.7 ± 8.4	114	2.3 ± 7.3

[a]Subjects with body mass index (BMI) ≥ 30 kg/m^2 were defined as obese.

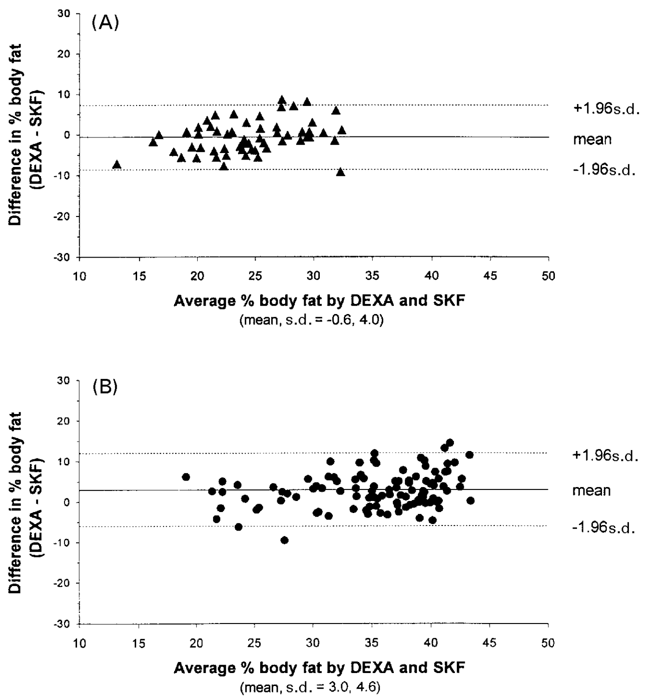

Figure 1 Plots of difference and mean values of % body fat estimated by dual-energy X-ray absorptiometric (DEXA) and skinfold thickness measurement (SKF) in 57 males (A) and 114 females (B). The solid lines indicate the bias, and the dashed lines indicate the limits of agreement between DEXA and SKF.

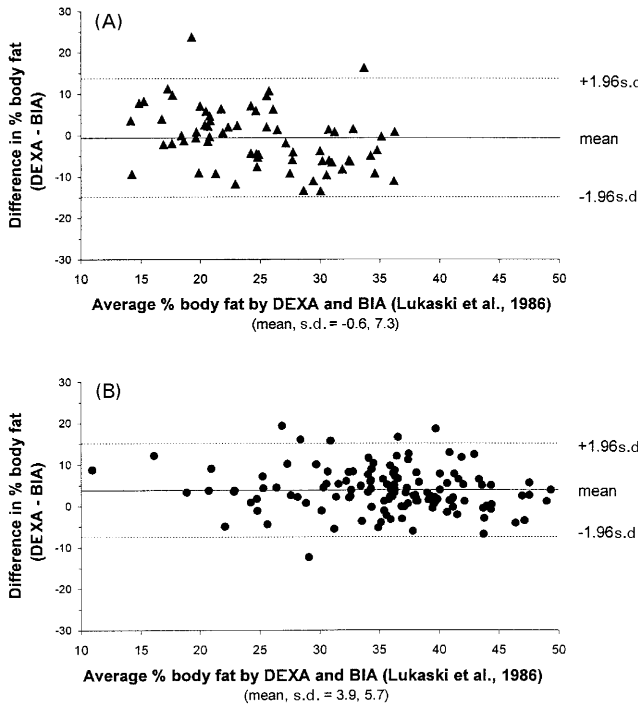

Figure 2 Plots of the difference and mean value of % body fat estimated by dual-energy X-ray absorptiometric (DEXA) and bioelectrical impedance analysis (BIA) with use of the equations of Lukaski *et al*,[14] in 66 males (A) and 130 females (B). The solid lines indicate the bias, and the dashed lines indicate the limits of agreement between DEXA and BIA.

employed in a number of studies.[5,8–10,13] Similarly, the correlation coefficient between values obtained from two methods, has also been used in many studies to asses the agreement between two methods.[4,9,17] However, it has been suggested that the use of correlation coefficients may not be appropriate because a high correlation does not reflect a high level of agreement.[4,9,16]

Agreement between DEXA and SKF for %BF estimation

A good agreement between DEXA and SKF has previously been reported in a younger population of 137 males and 128 females, aged 4–26 y.[8] Prediction equations accounting for the chemical immaturity of children and adolescents[18] were used for estimation of %BF by SKF. Similar to the present study, they found

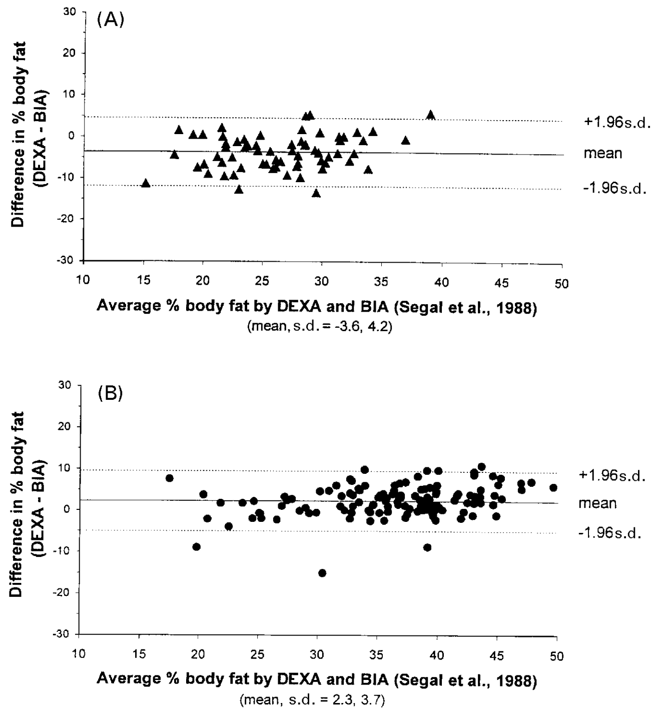

Figure 3 Plots of the difference and mean values of % body fat estimated by dual-energy X-ray absorptiometric (DEXA) and bioelectrical impedance analysis (BIA) with use of the equations of Segal *et al*,[15] in 66 males (A) and 130 females (B). The solid lines indicate the bias, and the dashed lines indicate the limits of agreement between DEXA and BIA.

no significant difference between %BF estimated by two methods in males, but an overestimate of SKF in females. A reduction of agreement between SKF and DEXA with increasing %BF, as shown in Figure 1, may in part explain a larger bias and wider limits of agreement between $\%BF_{SKF}$ and $\%BF_{DEXA}$ observed in females who had a higher %BF compared to males. The gender differences in the magnitude of bias between SKF and DEXA may result from the differential capability of these two methods to assess subcutaneous and visceral fat.

Pritchard *et al*[5] assessed the agreement between SKF and DEXA using an Hologic QDR 1000W whole-body X-ray densitometer (QDR) in a relatively small group of 12 healthy subjects (six males and six females), aged 19–58 y. They reported that the positive bias towards DEXA was 3.4% (95% CI: −7% to 3%). The discrepancy in the magnitude of bias, but not direction, between their study and the present study, may be due to the differences in the number and age-range of subjects, manufacturers of DEXA machines and probably %BF values of the study populations.

SKF is a long established method for estimating body fat[1] and widely used because it is easy, convenient, low cost and applicable in field studies. A low precision, however, can result from its high variability between observers.[19] Results from the present study and other studies[5,8] suggest that SKF is no less effective than DEXA in estimating %BF. This may encourage the application of SKF in %BF estimation. However, SKF tends to increasingly underestimate, %BF with increasing %BF. It is evident that the proportion of subcutaneous fat increases with increasing obesity, as summarised by Durnin and Womersley.[1] Therefore, there should be awareness of some methodological limitations in overweight or obese subjects. Similar to the present study, Gray *et al*[20] reported difficulties in obtaining satisfactory skinfold thickness measurements on obese subjects leading to an underestimation of %BF. A reduction in the agreement between DEXA and SKF, with increasing %BF, may partly be attributable to the different distribution of fat deposition with increasing %BF. It is evident that the proportion of subcutaneous fat increases with increasing obesity, as summarised by Durnin and Womersley.[1]

Results of the present study indicate that the method and formulae developed by Durnin and Womersley[1] over 20 years ago, are still applicable to Australians, even though there may be some changes in body fat distribution and fat patterning in the Australian population over the past 15 years. Furthermore, this SKF method including the prediction formulae has already proved to be applicable in populations with other ethnic origins, such as black Americans[21] and Chinese women,[22] despite the differences in fat distribution over the body.

Agreement between DEXA and BIA for %BF estimation

The manufacturer's equations notably underestimated %BF for both males (6.9%) and females (8.8%). These results were not comparable to those of Pritchard *et al*[5] who reported a good agreement between %BF estimated by BIA and DEXA using QDR. They observed that BIA, with use of the in-built RJL system software, underestimated %BF on average by 0.3% (95% CI: −3 to 5%).[5] As the results of the present study show, that the different equations used to predict %BF can produce a large variation in the bias between DEXA and BIA, ranging from 0.3–8.1%BF, it is possible that the difference in the results simply results from the difference in the equations used in these two studies. However, this could not be verified as the equations used in their study were not mentioned. They also reported that an instrumental difference between QDR and DPX was reflected in a 3.1% bias towards DPX for measurements of %BF.[5] Therefore, the difference in the results may in part result from the difference in densitometers and the equations used in these two studies. The number of subjects and their characteristics, such as age and body fatness, may also be one of other explanations.

The error in predicting FFM from BIA, has been previously reported to be related to obesity.[23] However, results from the present study show that the bias between DEXA and BIA in estimating %BF, with the use of the equations of Lukaski *et al*,[14] was not dependent on body fatness, even though a larger bias was observed in females compared to males.

In the present study, it was observed that, with respect to the agreement between BIA and DEXA, the equations of Segal *et al*[15] produced a smaller bias and a narrower limit of agreement either in total population or in females, compared to those of Lukaski *et al*.[14] This indicates a better applicability of Segal's equations especially to this population, compared to those of Lukaski *et al*. It is worth noting that Segal *et al*[15] suggested that resistance and height^2, individually, were better predictors of FFM than the calculated height^2/resistance.

DEXA as a criterion method

A number of studies have demonstrated that the precision of DEXA for %BF estimation, is greater than that of the underwater weighing method which is currently recognised as a 'gold standard' method.[3,5] It has been claimed that the DEXA technique could overcome problems of imprecision of SKF and BIA.[5] In contrast, the accuracy of DEXA in estimating %BF is inconclusive.[24] It has also been reported that there are differences between manufacturers of DEXA machines in measuring total body fat.[25,26] However, several studies, similar to the present study, used DEXA as a criterion method to compare with BIA or SKF.[9,10] In the absence of data from a gold standard method such as the underwater weighing method, it is not possible to assess the accuracy of the Lunar DPX whole-body X-ray densitometer, used in the present study. This study, however, can evaluate whether SKF or BIA is more or less accurate than DEXA in estimating %BF.

With respect to the applicability of SKF and BIA in estimating %BF in Australian adults, BIA does not offer advantage over SKF. Both of them meet many of the requirements, being non-invasive, relatively inexpensive and convenient. SKF might be adequate for some epidemiological and clinical estimates of body fatness, while BIA is valuable for body composition measurements requiring high precision. In addition, BIA provides reliable measurements with different untrained observers.[27] Although inter-observer variability of SKF can convert a low precision,[19] regular inter-observer quality control checks may help overcome this problem.

Conclusion

In estimating %BF in Anglo-Celtic Australians, there is a high level of agreement between SKF and DEXA. However, this agreement between SKF and DEXA is within the body fat range of the study population, because the agreement reduces with increasing %BF. The bias between BIA and DEXA varies depending upon the prediction equations. The equations developed by Segal *et al*[15] produce a better agreement compared to the other equations. Both BIA using their equations and SKF are equally applicable to estimate %BF in Anglo-Celtic Australian adults, when compared to DEXA.

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