Original Article

Validation of Body Fat Measurement by Skinfolds and Two Bioelectric Impedance Methods with DEXA — The Chennai Urban Rural Epidemiology Study [CURES-3]

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Abstract

Background and Objective : Although Asian Indians have been shown to have increased body fat compared to Europeans, there have been very few studies in Asian Indians validating the various methods available for body fat measurement. The aim of this study was to test the validity of body fat measured by two commercial impedance analyzers (leg-to-leg and hand-held) as well as by skinfolds with Dual Energy X-ray Absorptiometry (DEXA) as the reference method in a population based study in southern India.

Methods : Body fat percentage (BF%) was measured in 162 South Indian urban men (n=76) and women (n=86) randomly selected from the "Chennai Urban Rural Epidemiology Study" (CURES), an ongoing population based study of a representative population of Chennai. The mean age of the subjects was 45.1 ± 9.0 years and the body mass index ranged from 16.4 - 34.4 kg/m^2. Percentage body fat was measured using DEXA, segmental impedance (leg-to-leg: $BF\%_{IMP-LEG}$; and hand-held $BF\%_{IMP-HAND}$) using the manufacturer's software and skinfolds using the prediction equation from the literature ($BF\%_{SKFD}$).

Results : Body fat (%) determined by the leg-to-leg method ($BF\%_{IMP-LEG}$ 35.10 ± 7.26) and the skinfolds ($BF\%_{SKFD}$ 35.77 ± 6.06) did not differ significantly from the reference method DEXA ($BF\%_{DEXA}$ 35.82 ± 8.33), but the hand-held impedance method ($BF\%_{IMP-HAND}$ 31.38 ±6.24) showed significant difference ($p < 0.001$). The bias for estimation of body fat (%) for the bioimpedance leg-to-leg, hand-held and skinfolds were 0.73 ± 5.70, 4.45 ± 4.83 and 0.06 ± 5.86 respectively. All the three methods showed a fairly good correlation with DEXA ($BF\%_{IMP-LEG}$: $r = 0.741$, $p<0.001$; $BF\%_{IMP-HAND}$: $r = 0.817$, $p< 0.001$; $BF\%_{SKFD}$: $r = 0.710$, $p< 0.001$).

Conclusion : The study shows that in urban south Indians, measurement of body fat by the leg-to-leg impedance and the skinfold method have better agreement (lower bias) with DEXA than the hand-held impedance. However, all three methods (skinfolds, the leg-to-leg bioelectric impedance and hand-held impedance) show a fairly good correlation with DEXA. ©

INTRODUCTION

Prevalence rates of obesity are increasing all over the world, both among affluent and poor nations. Obesity related problems are now so common that they are replacing the earlier health concerns such as undernutrition and infectious diseases. Excess body fat is the hallmark of obesity.[1]

The human body is divided into two compartments consisting of fat and fat-free mass (FFM) and these are usually measured by indirect means.[2] In the absence of simple and accurate methods for assessing body fat directly, anthropometric indices such as body mass index (BMI) are often used as surrogates.[3] The relationship between BMI and percent body fat (BF%) differs among different ethnic groups and it is the amount of body fat, rather than the amount of excess weight, that determines the health risks of obesity such as type 2 diabetes mellitus and cardiovascular disease.[1] Asian Indians (South Asians) are unique in that while their BMI is lower than Europeans, abdominal obesity and body fat are higher.[4,5] In the Chennai Urban Population Study

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(CUPS) we showed that urban South Indians have a high risk for diabetes even with a low BMI (mean BMI 22.6 kg/m^2)[6] and this was confirmed by the DECODA study.[7] There is therefore an urgent need for assessing body fat for epidemiological studies among Asian Indians.

Skin fold thickness measurements provide fairly good estimates of body fat, but are largely dependent on the skill of the observer and hence can be subject to inter as well as intra-observer variations.[8] In the bioelectrical impedance method, a small alternating current is passed through the body to assess the total body water, from which the body fat percentage is derived.[9] Earlier studies have shown that segmental impedance measurements (measuring different parts of the body, such as the legs or the arms) also provide an assessment of body composition.[10]

However these methods need to be evaluated against a 'Reference Method' such as Dual Energy X-ray Absorptiometry (DEXA) or hydrodensitometry.[11] Hydrodensitometry (two compartment model) has long been considered as a reference method despite the fact that the fundamental underlying assumption, that the fractional composition of the fat-free mass (FFM- i.e., water, protein, minerals) is uniform across age and gender, probably makes it less accurate in some subgroups of the population, such as children and the elderly. DEXA has the advantage over hydrodensitometry of providing a measure of bone mineral mass in addition to fat mass and FFM (i.e. nonbone), thereby yielding a three-compartment model of body composition. DEXA is widely used because of its high precision and simplicity. The aim of the present study was to validate body fat measured by the skinfold method and two commercial impedance methods against DEXA (Reference method), in a population based study in southern India. Few such studies have been done in India which already has the largest number of diabetic patients in the world and this number is set to increase to 80.9 million by the year 2030.[12]

Material And Methods

The Chennai Urban Rural Epidemiology Study (CURES) is a large cross-sectional study done on a representative population of Chennai (formerly Madras) city in Southern India with a population of about 5 million people. The methodology of CURES has been reported elsewhere.[13] Briefly, the sampling for CURES was based on the model of systematic random sampling, wherein, of the 155 wards in Chennai, 46 wards were selected to provide a total sample size of 26,001 individuals ≥ 20 years of age. Phase I of CURES was conducted in the field, and involved a door-to-door survey in the selected wards. In Phase 2 all the known diabetic subjects and age and sex matched non-diabetic subjects were brought to our center for detailed anthropometric measurements and biochemical tests.

The data for this study was obtained from a sub study of CURES, which compared DEXA central abdominal fat with CT scan visceral fat in diabetic and non-diabetic subjects from the CURES Phase 2 and this is being reported separately.[14] For the present study, 162 subjects [76 males and 86 females] were included. The study group included 84 diabetic and 78 non-diabetic subjects. Informed consent was obtained from all subjects and the ethical committee of the centre approved the study.

Weight was measured to the nearest 0.1kg in light indoor clothing using a digital scale. Height was measured using a wall-mounted stadiometer to the nearest 0.1cm. BMI was calculated as weight (kg) / height m^2. Four skinfolds (biceps, triceps, subscapular and supra-iliac) were measured on the right side of the body. All measurements were standardized and carried out according to the Anthropometric Standardization Reference Manual.[15] Skinfold measurement was made to the nearest 1mm using skinfold caliper (Lange caliper, Cambridge Scientific Industry, Cambridge, Maryland). The logarithm of the sum of the four skinfolds was used in age and gender specific equations to obtain the body density (Durnin and Womersely, 1974), from which percentage body fat was calculated using Siri's formula.[16] A well-trained single observer took the measurements. The intra observer mean error was 0.09 mm ($p = 0.307$) and 95% confidence interval ranged from -0.09 to 0.29 mm for skin fold measurements, which were well within the acceptable limits.[15]

Bioelectric impedance measurements were made using two instruments. The Beurer body fat analyzer (Beurer BF 60, Ulm - Germany) incorporates weighing scales and measures both weight and bioimpedance. Subjects were asked to stand barefoot on the metal sole plates of the machine. Age, gender and height details were entered manually into the system. Impedance measurements allow assessment of the fat-free mass and by difference with body weight, assessment of body fat percentage.[9] Body weight and percentage body fat, estimated using the standard built in prediction equation for the given age group was displayed on the machine. A hand-to-hand impedance analyzer (Omron Body Fat Monitor, model HBF 302, Japan) was also used to measure the percent body fat. Details such as weight, height, age and sex were given as input into the instrument. This device was held while both arms were stretched horizontally in front of the body. Subjects refrained from food and drink for at least 6 hours and voided urine prior to the measurement session.[16] The reproducibility of the body fat measurement was assessed by repeating the measurements on 50 patients on the same day.

Whole body DEXA measurements were done after the bioelectric impedance measurements on the same day using Lunar prodigy (Model 8743 - BX/1L Madison, W.I, USA). Whole body DEXA (fan beam mode) was used to measure total body fat. DEXA consisted of scanning the body with X-rays of differing energy. The attenuation of these rays by body tissues was subjected to computer analysis to yield measures of total bone mineral, total body fat-free tissue, and body fat.[17] Subjects were scanned in light clothing while lying supine on their backs with arms at their sides. The DEXA examination included measurements of the whole body as well as in the trunk in three regions: (chest, abdomen, and pelvis), arms, and legs. Total body fat was measured for each subject in kilograms and in percentage.

Statistical analysis

Statistical analyses were performed using SPSS PC Windows version 10.0 (Chicago, IL). Outliers (n=7) removed before further analysis were done for the various body fat measurements. Therefore only 155 subjects were considered suitable for the subsequent analysis. The two types of method of body fat estimation i.e., skinfold and bioelectrical impedance (hand-held and leg-to-leg), were compared against DEXA using analysis of bias. Measures obtained by the skinfolds or bioelectrical impedance methods are subtracted from the same measures obtained from DEXA and the mean ± SD of these differences (bias) are calculated. 95% limits of agreement are obtained as the mean ± 1.96 SD. Bland and Altman plots are used to visualize the validity of measured BF% of each method[18] and paired 't' test was used to look for specific differences between the methods. Subjects were categorized (based on the mean age) into two age groups (≤ 45 and > 45 yrs), gender, BMI (BMI ≤ 22.9; 23 - 24.9 and ≥ 25 kg/m^2 based on Asia Pacific guidelines) and abdominal obesity - waist circumference ≥ 90 cm for males and ≥ 80 cm for females.[19] Correlation coefficient (r) was obtained for these categories.

Results

Body fat percent in the study population by different methods

Table 1 shows the total body fat percent by different methods. Body fat (%) measured by leg-to-leg impedance and skinfold methods did not show significant difference from the reference method DEXA ($BF\%_{IMP-LEG}$ p=0.115; $BF\%_{SKFD}$ p=0.906), while the hand-held impedance method showed significantly lower values from DEXA (p <0.001).

Reproducibility

The reproducibility of the two bioimpedance methods was determined by repeating the body fat measurements on 50 individuals by the same methods on the same day. There was no significant difference between the two measurements as assessed by paired t test hand-held impedance (p=0.137) and leg-to-leg impedance (p=0.206) confirming good reproducibility and precision.

Table 1: Physical characteristics of the study population

Variables	Mean ± SD (n = 155)
Age (years)	45.1 ± 9.0
Height (cm)	159.4 ± 8.4
Weight (kg)	63.9 ± 11.5
Body mass index (kg/m^2)	25.1 ± 3.9
Waist circumference (cm)	90.1 ± 10.0
Hip circumference (cm)	97.4 ± 9.4
Waist to hip ratio	0.93 ± 0.07
$BF\%_{DEXA}$	35.82 ± 8.33
$BF\%_{IMP-LEG}$	35.10 ± 7.26 (p = 0.115)
$BF\%_{IMP-HAND}$	31.38 ± 6.24 (p < 0.001)
$BF\%_{SKFD}$	35.77 ± 6.06 (p = 0.906)

p values are based on paired t test in comparison with DEXA. $BF\%_{DEXA}$, percent body fat measured using Dual Energy X-ray Absorptiometry (DEXA); $BF\%_{IMP-LEG}$ and $BF\%_{IMP-HAND}$, percent body fat measured using bioimpedance leg to leg and hand held respectively; $BF\%_{SKFD}$, percent body fat measured using skinfold thickness.

Bias

The mean differences between the reference method and other methods of body fat assessment were computed, in which the hand-held impedance method had the maximum bias from DEXA compared to leg-to-leg impedance and skinfold method. Bland and Altman plots were used to show the bias of each method (Figs. 1a,b,c). The mean bias predicted for the $BF\%_{IMP-LEG}$ (Fig. 1a) was +0.73% and the 1.96SD ranged from -10.44 to +11.90. The mean bias for the $BF\%_{IMP-HAND}$ (Fig. 1b) was +4.45% and 1.96SD ranged from -9.47 to +13.92. The mean bias for the $BF\%_{IMP-SKFD}$ (Fig. 1c) was 0.06% and the 1.96SD ranged from -11.43 to +11.55.

Correlation

In the total study population, all the three methods showed a strong correlation with DEXA (p < 0.001) with r values of 0.741 for leg-to-leg impedance method, 0.817 for hand-held impedance method and 0.710 for skinfolds.

The correlation of the three methods when the subjects were stratified according to age (≤ 45 years and > 45 years), sex (male and females), three BMI categories (BMI ≤ 22.9; 23 - 24.9 and ≥ 25 kg and abdominal obesity based on waist circumference as (≥ 90 cm for males and ≥ 80 cm for females)[19] and presence or absence of diabetes are presented in Table 2. The body fat (%) measured by leg-to-leg impedance showed a good correlation with DEXA, the r values ranging from 0.385 to 0.772, while it ranges from 0.565 to 0.886 for the hand-held impedance and for skinfolds from 0.370 to 0.769.

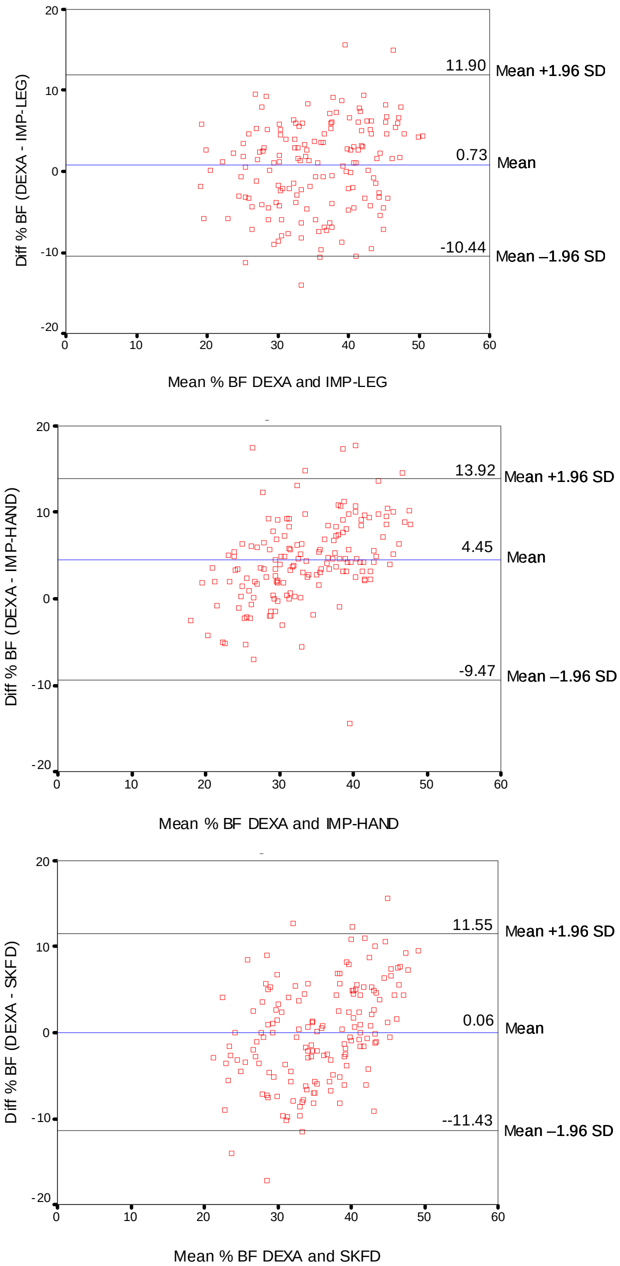
Discussion

Since the advent of DEXA, this technique has been widely used for measuring total body fat[11] and hence we chose this as our reference method. Because the total radiation dose is

Table 2 : Correlation of different methods compared with DEXA

		Correlation coefficient (r)		
		$BF\%_{IMP-LEG}$	$BF\%_{IMP-HAND}$	$BF\%_{SKFD}$
Age	Age ≤ 45 years (n = 88)	0.758	0.788	0.769
	Age > 45 years (n = 67)	0.737	0.855	0.690
Sex	Males (n = 73)	0.500	0.621	0.370
	Females (n = 82)	0.385	0.665	0.416
BMI	Non-obese (n = 46)	0.709	0.634	0.614
	Overweight (n = 28)	0.751	0.824	0.761
	Obese (n = 81)	0.730	0.818	0.683
Waist circumference	Normal (n = 47)	0.725	0.565	0.593
	Abdominal obesity (n = 108)	0.735	0.814	0.646
Glucose tolerance	Normal (n = 82)	0.706	0.740	0.718
	Diabetes (n = 73)	0.772	0.886	0.715

p < 0.001 for all the categories. BMI categories: Non-obese ≤ 22.9; Overweight 23 - 24.9; Obese ≥ 25 kg/m^2, abdominal obesity: waist circumference: ≥ 90 cm for males and ≥ 80 cm for females. $BF\%_{DEXA}$, percent body fat measured using Dual Energy Xray Absorptiometry (DEXA); $BF\%_{IMP-LEG}$ and $BF\%_{IMP-HAND}$, percent body fat measured using bioimpedance leg to leg and hand-held respectively; $BF\%_{SKFD}$, percent body fat measured using skinfold thickness.



Figs. 1: Bland Altman plot of body fat percent (bias) of two bioimpedance methods and skinfolds with the reference method (DEXA). a: Impedance leg-to-leg model (IMP-LEG) vs DEXA. b: Impedance hand-held model (IMP-HAND) vs DEXA. c: Skinfold method (SKFD) vs DEXA

extremely low, the method can be used for research purposes across all age groups except in pregnant women. It is also far easier to perform than underwater weighing. However, it is expensive and time consuming and hence unsuitable for large epidemiological studies particularly in developing countries.

Skinfolds are the most widely used technique to measure body fat in epidemiologic studies. Various sites of measurement have been suggested, and probably the best-established and frequently reported method is the one using four sites: biceps, triceps, subscapular and suprailiac. This was developed by Durnin and Womersley[16] to calculate body density and further, using Siri's (two compartment model) formula, to calculate the body fat percentage. The limitation of this method is that the measurements are subject to considerable variation between observers.[15] With skilled observers and particularly if a single observer performs the study, as in this study the variation could be drastically reduced. However using a single observer is difficult if large number of people are to be screened.

Bioelectric impedance analysis is a useful technique for body composition analysis in healthy individuals and in those with a number of chronic conditions such as obesity, diabetes mellitus, and other medical conditions in which major disturbances of water distribution are not present.[9]

Earlier studies have reported both under and overestimation of body fat by impedance measurements as compared to DEXA.[20] These differences might relate to the different impedance devices used and the in built unknown prediction equations which could also result in measurement differences between different machines. Prediction equations for body composition tend to be population-specific due to differences in predictors among population groups. However it is virtually impossible for such population specific formula to be built into the instrument as there might be as many equations needed as there are population groups.[21] In this study we tried to validate the measurements through the built in equations of two impedance models (Leg-to-leg: Beurer, Germany and hand-held Omron, Japan, Asian model) and we observed that the leg-to-leg impedance method and the skinfolds showed better agreement than the hand-held impedance with DEXA. However, all the three methods showed a good correlation with DEXA even when the subjects were categorized based on age, BMI, abdominal obesity and presence or absence of diabetes.

In conclusion, the leg-to-leg impedance and the skinfolds have a better agreement (lower bias) with DEXA than the hand-held impedance. All the three methods (skinfolds, the leg-to-leg bioelectric impedance and hand-held impedance) show a fairly good correlation with DEXA for the measurement of body fat, although, each has its own advantages and disadvantages. These methods have potential for widespread use because of their simplicity and low cost and any method can be used depending on the resources available. However, it is better to adhere to one method to assess body fat in different study groups so that the inherent disadvantage of the method would not affect the validity of the results. Additional studies are needed for predicting adiposity in the elderly, the very lean (BMI < 16.4 kg/m^2), and the morbidly obese (BMI > 34.4 kg/m^2) as these groups were not tested in this study.

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