

Measurements of body fat in Indonesian adults: Comparison between a three-compartment model and widely used methods

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Body composition was assessed in Indonesian male ($n = 18$) and female ($n = 23$) students using densitometry (underwater weighing), deuterium oxide dilution, skinfold thickness measurements, bioelectrical impedance analysis (BIA) and a prediction equation based on the body mass index. From body density and total body water percentage body fat (BF%) was calculated using a three-compartment body composition model. Percentage body fat obtained by this three-compartment model was regarded as the reference value and BF% obtained by the single methods were compared with this value. Mean differences (\pm SD) in BF% from the three-compartment model minus the single methods were -1.1 ± 2.1 for densitometry, $+1.1 \pm 1.6$ for deuterium oxide dilution, $+1.3 \pm 2.8$ for skinfold thickness measurement, $+2.8 \pm 4.3$ for BIA and $+3.4 \pm 4.8$ for body mass index in males. In females these values were $+0.1 \pm 1.7$, $+0.2 \pm 1.4$, $+3.6 \pm 3.3$, $+3.6 \pm 2.4$ and $+8.7 \pm 2.0$ BF%, respectively. Correlation coefficients between different methods were high and significant ($P < 0.05$ in males, $P < 0.001$ in females). This study shows that the single predictive methods have considerable mean and individual biases compared with the three-compartment model and all predictive methods underestimated body fat in the studied subjects. It is concluded that the development of population-specific prediction formulas may be necessary.

Key words: body composition, body fat, densitometry, deuterium oxide dilution, bioelectrical impedance, skinfolds, body mass index, Indonesia

Introduction

There are numerous methods available to assess human body composition, which is an important indicator of nutritional status. However, only a few methods can be considered as field-applicable or suitable in clinical practice, which requires the application of simple equipment, low costs and the fact that they are non-invasive and not time consuming. To these methods belong bioelectrical impedance analysis (BIA)¹ and anthropometry such as skinfold thickness measurements² and body mass index (BMI), defined as body weight/height² (kg/m^2). These latter methods enable the assessment of body fat (BF) or fat free mass (FFM) based on statistical relationships between easy measurable body parameters and a method of reference. The prediction formulas described in the literature are mostly developed in Caucasian populations and it may be questioned whether these formulas are valid in populations with other ethnic backgrounds because of differences in body composition. Studies among the Asian population show a higher body fat level at any given BMI³ compared with Caucasians while the opposite seems to be true for Blacks who have a greater bone and muscle values.^{4,5} Furthermore, comparisons between black and white populations

indicate that fat patterning and fat distribution differs among ethnic groups.^{6,7} Some studies also indicate differences in the relationship between body composition and body impedance in different ethnic groups.^{8–10}

Commonly used reference methods for the measurement of fat mass (FM) or FFM are hydrodensitometry and deuterium oxide dilution, methods based on the classical two-compartment model.^{1,11,12} The densitometric method assumes a constant density of the FM of 0.9 kg/L and of the FFM of 1.1 kg/L .¹¹ Deuterium oxide dilution assumes a constant hydration factor of the FFM of 0.73.¹² A three-compartment model, obtained by combining densitometry and deuterium oxide dilution, balances the possible bias of the water fraction assumptions of both methods¹³ and therefore improves the accuracy of body composition measurements.

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In the present study percentage body fat (BF%) measured by densitometry, deuterium oxide dilution, anthropometry and bioelectrical impedance analysis was validated against a three-compartment model as a reference in a group of Indonesian adults. The aim of this study was to obtain information about the validity of predictive methods for body fat in Indonesian adults.

Subjects and methods

The study was performed at the SEAMEO-TROPED Regional Centre for Community Nutrition of the University of Indonesia, Jakarta. Body composition was measured in 45 apparently healthy Indonesian adults, 22 males and 23 females, aged 18–42 years, recruited from different institutes of the University. After all procedures had been explained to the subjects their written informed consent was obtained. The study protocol was approved by the Medical Ethical Committee of the Faculty of Medicine, University of Indonesia, Jakarta.

Four subjects (all males) were excluded from statistical analysis because the difference between percentage body fat from densitometry and from deuterium oxide dilution was larger than 13% body fat (> 2 SD), indicating a non-valid body fat measurement of at least one of the two applied methods. All measurements were done on the same day, at least 2 h after a meal.

Body weight was measured to the nearest 0.1 kg using a digital scale (Seca 700, Hamburg, Germany). Height was measured to the nearest 0.1 cm with a wall-mounted stadiometer. Body mass index was computed as weight/height² (kg/m²). From BMI, body fat was calculated using an age- and sex-specific prediction formula, derived in a Dutch population:¹⁴

Percentage body fat = $1.2 \times \text{BMI} + 0.23 \times \text{age} - 10.8 \times \text{sex} - 5.4$, where age is in years and sex is 1 for males and 0 for females.

Body density was established by underwater weighing in a tiled tank in which a swing seat was suspended from a Salter (model 235, London, UK) spring scale. The subjects were instructed according to the principles described by Behnke and Wilmore to exhale maximally, then to submerge and remain as motionless as possible for about 5 s while underwater weight was recorded to the nearest 0.1 kg.¹⁵ After several trials to familiarize the subjects with the test procedure, 10 measurements were performed. The estimated underwater weight was the highest value that was reproduced at least three times. Water temperature, to account for its effect on water density, and the weight of the equipment were recorded after each session. The net underwater weight was weight of equipment subtracted from weight of subject plus equipment.

Residual lung volume was measured by nitrogen dilution using a closed circuit approach modified after Wilmore.¹⁶ While sitting in an imitate position compared to the actual underwater weighing, the subjects were asked to exhale maximally and then to take three deep respirations from a Douglas bag, filled with 2 L of pure nitrogen. The oxygen content of the Douglas bag was measured using a Servomex 570A (Crowborough, East Sussex, UK) oxygen analyser. Replicate determinations of the residual lung volume made on nine subjects agreed within 54 ± 40 mL compared to an aver-

age residual lung volume of 900 ± 310 mL. The maximum difference resulted in an error of about 1% (relative to weight) body fat. Therefore, only one determination of residual lung volume was performed routinely per subject. Body density was calculated with the formula of Goldman and Buskirk¹⁷ and transformed to percentage body fat by use of the Siri equation ($\text{BF}\% = 495/D_b - 450$, where D_b is body density).¹¹

Total body water (TBW) was determined by deuterium oxide dilution. An accurately (to the nearest 0.01 g) weighed dose of 10 g deuterium oxide was orally administered and after 2.5–3 h dilution time a venous blood sample of 10 mL was drawn. The plasma was separated and stored at -20 °C until analysis at the laboratory of the Department of Human Nutrition, Agricultural University Wageningen. Deuterium in plasma was determined after sublimation by infrared spectroscopy.¹⁸ Total body water (kg) was calculated using a correction factor (0.95) for non-aqueous dilution.¹² From TBW the FFM was calculated assuming a hydration fraction of 0.73¹² and BF% was calculated as $100 \times (\text{weight} - \text{FFM})/\text{weight}$.

From body density and TBW, BF% was computed using the three-compartment model described by Siri:¹¹

$$\text{BF}\% = 100 \times (2.118/D_b - 0.78 \times A - 1.354)$$

where D_b is body density and A is the water fraction of body weight. BF% calculated with this three-compartment model is regarded as the method of reference in this paper.

Skinfold thickness measurements by using a Holtain caliper (Holtain Ltd, Crymch, Dyfed, UK) were performed at the left side of the body according to Durnin and Womersley.² Each skinfold (biceps, triceps, subscapular, supra-iliac) was measured in triplicate and the mean values were used in calculations.

A multi-frequency impedance analyser (Humanim Scan, Dietosystem, Milano, Italy) was used to obtain total body impedance at 50 kHz. The measurement was performed while lying supine on a non-conductive surface with the limbs slightly abducted and the arms not touching the trunk. The self-adhesive electrodes (Littman 3M, 2325 VP, St. Paul, MN, USA) were attached on the left hand and the left foot according to Lukaski *et al.*¹⁹ Single measurements were performed as the reproducibility of the impedance measurements is known to be very high.¹ From height and impedance the impedance index (height²/Z, cm²/Ω) was computed. To calculate BF% from impedance the formulas of Lukaski *et al.*,¹⁹ Segal *et al.*²⁰ and Deurenberg *et al.*²¹ were applied.

The SPSS program²² was used for statistical calculations. Differences between measured and predicted body fat percentage were tested by paired *t*-test and with the technique described by Bland and Altman.²³ Correlations are Pearson's product-moment correlations. A probability of < 0.05 is regarded to be significant. All results are expressed as mean \pm standard deviation (SD).

Results

Table 1 shows some characteristics of the subjects. Males were older and body weight and body height were significantly higher. Body mass index did not differ between the sexes. Females had significantly more body fat compared with males. All four skinfolds were significantly thicker in females and body impedance was higher.

Table 1. Characteristics of the subjects

| | Males (<i>n</i> = 18) | | Females (<i>n</i> = 23) | |
|---------------------------------|------------------------|------|--------------------------|------|
| | Mean | SD | Mean | SD |
| Age (years) | 28.1 | 6.6 | 21.2* | 2.9 |
| Weight (kg) | 60.4 | 9.2 | 50.4* | 9.5 |
| Height (m) | 1.68 | 0.05 | 1.54* | 0.05 |
| BMI (kg/m ²) | 21.4 | 3.0 | 21.1 | 3.0 |
| Body fat (%) ^a | 19.4 | 5.4 | 33.6* | 4.8 |
| Fat free mass (kg) ^a | 48.3 | 4.9 | 33.1* | 3.9 |
| Fat mass (kg) ^a | 12.1 | 5.5 | 17.3* | 6.0 |
| Skinfolds (mm) | | | | |
| Triceps | 12.6 | 5.8 | 19.1* | 5.0 |
| Biceps | 4.4 | 2.4 | 8.6* | 4.2 |
| Subscapular | 13.7 | 5.0 | 19.2* | 7.2 |
| Supra-iliac | 13.9 | 8.4 | 19.8* | 5.9 |
| Sum skinfolds | 44.6 | 19.8 | 66.7* | 20.9 |
| Impedance (Ω) | | | | |
| 50 kHz | 508 | 59 | 647* | 62 |

^aCalculated from three-compartment model; * *P* < 0.05, significantly different from males.

Table 2. Differences between per cent body fat from three-compartment model and per cent body fat from single methods.

| | Males (<i>n</i> = 18) | | Females (<i>n</i> = 23) | |
|--------------------------------|------------------------|-----|--------------------------|-----|
| | Mean | SD | Mean | SD |
| Three-compartment model minus: | | | | |
| Body density | -1.1 | 2.1 | 0.1 | 1.7 |
| D ₂ O-dilution | 1.1 * | 1.6 | 0.2 | 1.4 |
| Skinfolds ^a | 1.3* | 2.8 | 3.6** | 3.3 |
| BMI ^b | 3.4** | 4.8 | 8.7** | 2.0 |
| Impedance ^c | 2.8* | 4.3 | 3.5** | 2.4 |

*, *P* less than 0.05; **, *P* less than 0.01 significantly different from three-compartment model.

^aformula: reference 2; ^bformula: reference 14; ^cformula: reference 21.

Differences between measured and predicted body fat are listed in Table 2. Body fat from all single methods was significantly different from the reference value, except body fat from body density in both sexes and body fat from deuterium oxide dilution in females. The predictive methods generally underestimated body fat. The large difference between BF% estimated from BMI and the reference value in females was remarkable. Body fat from impedance, using the prediction formulas from Lukaski *et al.*¹⁹ and Segal *et al.*²⁰ also underestimated body fat in males with 5.8 ± 6.6 and 5.3 ± 4.7%, respectively, and in females 4.8 ± 4.2 and 8.0 ± 5.1%, respectively. In Table 3 the correlation coefficients between all body fat measures are given for males and females separately. The correlation coefficients in males ranged from 0.63 to 0.97 and in females from 0.75 to 0.97. The correlation coefficients between the methods were generally slightly higher in females.

Figure 1 shows the individual differences of the single methods with the method of reference. All predictive

Table 3. Correlation coefficients between body fat from three-compartment model and single methods

| Males/Females | BF _{3 cm} | BF _{dens} | BF _{D2O} | BF _{sf} | BF _{bmi} | BF _{imp} |
|--------------------|--------------------|--------------------|-------------------|------------------|-------------------|-------------------|
| BF _{3 cm} | — | 0.94 | 0.97 | 0.76 | 0.93 | 0.87 |
| BF _{dens} | 0.94 | — | 0.82 | 0.69 | 0.87 | 0.80 |
| BF _{D2O} | 0.97 | 0.83 | — | 0.75 | 0.90 | 0.86 |
| BF _{sf} | 0.89 | 0.87 | 0.84 | — | 0.86 | 0.83 |
| BF _{bmi} | 0.63 | 0.65 | 0.57 | 0.82 | — | 0.92 |
| BF _{imp} | 0.75 | 0.78 | 0.67 | 0.88 | 0.86 | — |

All values significant (*P* < 0.05).

BF_{3 cm}, body fat per cent from three-compartment model; BF_{dens}, body fat per cent from density; BF_{D2O}, body fat per cent from deuterium oxide dilution; BF_{sf}, body fat per cent from skinfolds; BF_{bmi}, body fat per cent from BMI; BF_{imp}, body fat per cent from impedance.

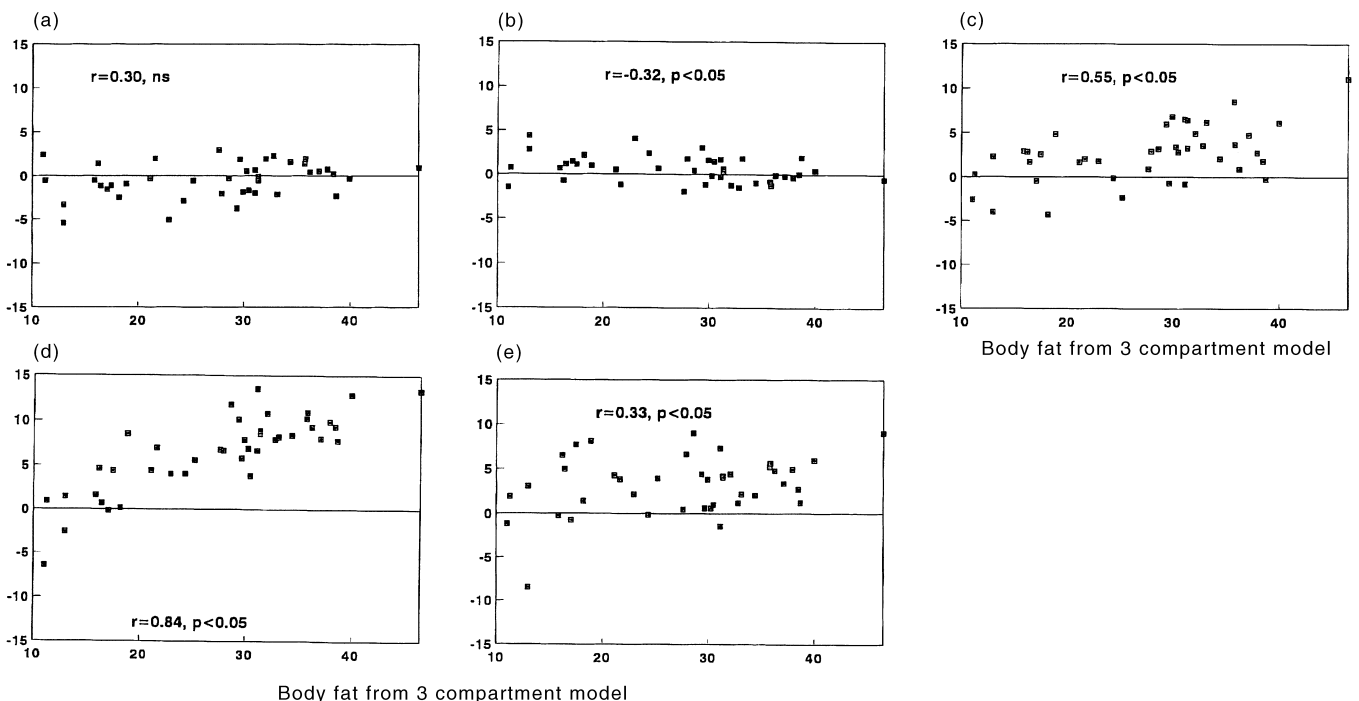


Figure 1. Individual differences between body fat percentage obtained by the reference method and the single methods. (a) Reference minus densitometry; (b) reference minus deuterium dilution; (c) reference minus skinfolds; (d) reference minus body mass index; (e) reference minus impedance.

methods (i.e. skinfolds, BMI, and to a lesser extent bio-electrical impedance) underestimated percentage body fat more strongly at higher levels of body fat.

Discussion

In this study body composition was measured in random, apparently healthy students, recruited from several faculties of the University of Indonesia in Jakarta. They were not only Javanese, but came partly from other Indonesian islands. The number of subjects was limited by the available funding. A much larger sample would be necessary for a complete survey of Indonesian adults and the various ethnic groups.

Table 1 shows normal differences between males and females in body composition parameters, males being taller and having a higher body weight, but a lower relative body fat content. The relatively high percentage body fat compared with the body mass index, both in males and females, is striking.

Percentage body fat was estimated using several methods. As a method of reference, body fat was obtained by a three-compartment model.¹¹ Siri estimated the maximal error of a two-compartment model, consisting of FM and FFM, to be about 4% of body weight.¹¹ Most of this error can be attributed to biological variability in the composition of the FFM and only a small fraction to measurement error. A three-compartment model, consisting of FM, water and 'dry' FFM (in fact protein and mineral) has a maximal mean error of about 2% of body weight, according to Siri's calculations.¹¹ In the present study the maximal individual error of the two-compartment model compared to the three-compartment model as a reference was about 6% in males and 3% in females for densitometry and for deuterium oxide dilution 9% in males and 3% in females, whereas the mean errors for densitometry were -0.7 and +0.1% in males and females, respectively, and +1.6 and +0.2% for deuterium oxide in males and females, respectively.

The three-compartment body composition model is a relatively cost-effective approach to improve the accuracy of body composition estimate because it reduces the opposite influence of the water fraction assumption in the two-compartment model.¹³ A four-compartment model as described by Baumgartner *et al.*,²⁴ including FM, TBW, mineral and a remaining compartment, consisting of protein and carbohydrate, is theoretically a better approach, but the addition of mineral (measured by Dual Energy X-ray Absorptiometry) as an independent variable in the four-compartment model provides only a small increase in accuracy at a relatively high price.^{24,25}

In the present study densitometry slightly underestimated BF% in females whereas in males densitometry overestimated BF% (Table 2). This overestimation in males may be due to differences in the water and mineral fraction of the FFM, meaning that the assumption of a density of the FFM of 1.1 kg/L may be not applicable for the present sample. More research with respect to mineral and/or water fraction in the fat free mass is necessary to clear this finding.

Although the correlation between estimates of percentage body fat were high (Table 3), mean and individual differences between the separate methods were high (Table 2, Fig. 1). Predicted mean values of body fat from skinfolds, BMI and impedance were all lower than the reference value. The underestimation of BF% from skinfolds, impedance and BMI was higher in females than in males. An explanation for the lower percentage body fat from skinfolds may be a different fat distribution.⁷ If the assumed ratio of internal to subcutaneous fat is different, or if the subcutaneous fat pattern is different compared to the Scottish population in which the formulas were developed,² the prediction formulas will give biased results. However, it cannot be excluded that the difference may also be due to measurement error (i.e. different standardization).

The BMI values for males and females are lower compared to studies performed in Caucasian subjects,² but body fat values are much higher, especially in females. The finding that the relationship between BF% fat and BMI in the present study group is different compared to the Caucasian population is in agreement with results from another study.³ This may have important practical implications for public health policies with regard to prevalence figures for obesity based on BMI and warrants further investigation.

Also body fat predicted from body impedance is underestimated using Caucasian prediction formulas. In the present population the amount of extracellular water was relatively high (results not shown, see ²⁶), resulting in a biased too low impedance value at 50 kHz and consequently in an overestimation of FFM, thus an underestimation of FM and BF%.²¹ However, other factors as a different electrode placement and a different ambient and/or body temperature could be, in part, responsible for the bias.²⁷

As shown in Fig. 1 all predictive methods show a positive correlation of the bias (measured minus predicted BF%) with the method of reference, indicating that, especially at higher levels of body fat, the predictive methods underestimate the body fat content. This was also found in other studies^{28,29} and is in accordance with James *et al.*³⁰

In summary, BF% values obtained from skinfold thickness measurement, body impedance and BMI sometimes showed marked differences, especially at an individual level, from BF% obtained by a three-compartment body composition model in which the variations in body water were accounted for. The study shows that BMI and bioimpedance may be useful in many situations, but they rely on calibration in a similar population and should be used with caution. The results are convincing only because the reference techniques of underwater weighing and deuterium oxide dilution have been used. This demonstrates the need for research laboratories to be equipped with 'gold standard' methods in countries such as Indonesia.

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印度尼西亞成人體脂的測量 三個隔間模型和廣泛應用的方法比較

摘 要

作者用密度法（水下秤重），氧化重氫稀釋法，皮褶厚度測量，生物電阻抗分析（BIA）和基於體重指數的預測公式評估了印度尼西亞男學生（18人），和女學生（23人）的身體組成。用三部份隔間身體組成模型計算身體密度和身體脂肪百分數（BF%）。從三個隔間模型得出的BF%作為參考值，與單一方法測得的BF%相比較，即前者減去後者，男學生平均BF%差異分別為：-1.1±2.1（密度法），+1.1±1.6（氧化重氫稀釋法），+1.3±2.8（皮褶厚度測量法），+2.8±4.3（生物電阻抗法）和+3.4±4.8（體重指數法）。女學生的BF%差異分別為：+0.1±1.7、+0.2±1.4、+3.6±3.3、+3.6±2.4和+8.7±2.0。不同方法測得的關係系數有明顯差異（男學生P<0.05，女學生P<0.001）。該研究顯示單一方法測得的體脂百分數均較三個隔間模型測得的結果為低。因此作者認為，也許需要建立測定BF%的人群特殊預測公式。

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