Original Article

Development and validation of anthropometric prediction equations for estimation of body fat in Indonesian men

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Body composition of 292 males aged between 18 and 65 years was measured using the deuterium oxide dilution technique. Participants were divided into development (n=146) and cross-validation (n=146) groups. Stature, body weight, skinfold thickness at eight sites, girth at five sites, and bone breadth at four sites were measured and body mass index (BMI), waist-to-hip ratio (WHR), and waist-to-stature ratio (WSR) calculated. Equations were developed using multiple regression analyses with skinfolds, breadth and girth measures, BMI, and other indices as independent variables and percentage body fat (%BF) determined from deuterium dilution technique as the reference. All equations were then tested in the cross-validation group. Results from the reference method were also compared with existing prediction equations by Durnin and Womersley (1974), Davidson *et al* (2011), and Gurrici *et al* (1998). The proposed prediction equations were valid in our cross-validation samples with r=0.77-0.86, bias 0.2-0.5%, and pure error 2.8-3.6%. The strongest was generated from skinfolds with r=0.83, SEE 3.7%, and AIC 377.2. The Durnin and Womersley (1974) and Davidson *et al* (2011) equations significantly (p<0.001) underestimated %BF by 1.0 and 6.9% respectively, whereas the Gurrici *et al* (1998) equation significantly (p<0.001) overestimated %BF by 3.3% in our cross-validation samples compared to the reference. Results suggest that the proposed prediction equations are useful in the estimation of %BF in Indonesian men.

Key Words: anthropometry, prediction equation, deuterium oxide dilution, body fat, Indonesia

INTRODUCTION

Body composition is an important indicator of nutritional status. However, precise and accurate body composition assessment techniques such as the deuterium dilution technique (D_2O) and dual-energy X-ray absorptiometry (DXA) are generally challenging and require expensive instruments as well as specifically trained technicians. Consequently, these techniques are only suitable for laboratory-based studies. Many studies have reported the estimation of body composition including percentage body fat (%BF) using anthropometry (eg skinfolds, circumferences).[1-6] While these studies use prediction equations, these equations are mostly developed from Caucasian populations. Since body composition prediction equations are population-specific, it is inappropriate to apply such approaches in the estimation of body composition in different ethnic groups.[7,8] For example, the formula of Durnin and Womersley[9] has been shown to underestimate %BF in Indonesian populations using a three-compartment model[10] and D_2O technique.[11,12] Davidson *et al* [2] modified the formula of Durnin and Womersley[9] for different racial groups, including Asians, however no studies have cross-validated this equation using an Indonesian population. The equation by Gurrici *et al* [11] is the only equation developed from an Indonesian population to predict body fatness using BMI, however this equation has not been cross-validated since its development.

The D_2O dilution technique can accurately predict total body water (TBW)[13] from which fat-free mass (FFM) can be calculated assuming a constant hydration of FFM in the two-compartment model.[13,14] D_2O has been used as a

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Manuscript received 27 February 2013. Initial review completed 15 April 2013. Revision accepted 6 July 2013.
doi: 10.6133/apjcn.2013.22.4.14

reference method to assess body composition in many studies, including the accurate determination of FFM against the four-compartment (4C) model in Mexican youth[15] and %BF against the three-compartment (3C) model in Indonesian females.[10]

To date, no prediction equations using anthropometry exist for Indonesian adults, except for the BMI equation by Gurrici *et al.*[11] In addition, some anthropometric measures and indices such as waist circumference (WC), waist-to-stature ratio (WSR), and waist-to-hip ratio (WHR) are also suggested as better indicators of obesity compared with BMI.[16] Hence, it is important to develop %BF prediction equations that utilize anthropometric variables other than BMI, therefore the aim of the present study was to develop and validate %BF prediction equations using anthropometric variables with D_2O technique as a reference method. The study also evaluated the validity of a number of existing prediction equations.

MATERIALS AND METHODS

Participants

Participants were recruited from Javanese populations living in Yogyakarta Special District, Indonesia. Two hundred and ninety-two healthy males aged 18-65 years participated in the study. Sample size was determined using the formula of Whitney and Ball.[17] Ethical approval was obtained from the Human Research Ethics Committee of Queensland University of Technology, Australia and Gadjah Mada University, Indonesia. All participants provided written informed consent. Participants were instructed to fast overnight and avoid physical exercise and excessive sweating prior to the day of the measurement.

Anthropometry

Stature was taken using a *microtoise* (Johnson and Johnson Co Ltd) to the nearest 0.1 cm. Body weight was measured with the participant wearing light clothing using a Seca weight scale (Seca 803, Seca Deutschland) to the nearest 0.1 kg. Skinfold thickness was measured at eight sites (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf) using a Harpenden calliper. Breadth measurements at biacromial, biiliocristal, humerus, and femur were taken using sliding callipers (GPM Swiss). Five girth measures (arm relaxed, arm flexed and tensed, minimum waist, gluteal, and maximum calf) were taken using an anthropometric tape (Holtain Rinehart Co. Ltd.). All measurements were conducted using the standard protocol of the International Society for the Advancement of Kinanthropometry (ISAK)[18] by an accredited ISAK level 1 anthropometrist. Technical error of measurement (TEM) was calculated for the first 20 participants and indicated that all measures were within target intra-tester TEM values (below 7.5% for skinfolds and below 1.5% for other measures).[19]

Deuterium oxide (D_2O) dilution

The D_2O dilution technique was used to assess TBW following the protocols of Heyward and Wagner[14] and the International Atomic Energy Agency (IAEA).[20] This method measures the degree of dilution of a known dose of deuterium after it has equilibrated in body fluid. A 100 mL D_2O (99.9 atom % D; Aldrich Chemistry, Sigma-Aldrich Pty Ltd) was added into 900 mL tap water to make a 10% deuterium solution. Participants were given the 10% deuterium solution based on their body weight after collecting a 10 mL pre-dose urine sample. A second 10 mL urine sample was collected 6 hours later. Urine samples were subsequently analysed using an isotope ratio mass spectrometry (IRMS-Hydra 20-20 SerCon Mass Spectrometry) at the Institute of Health and Biomedical Innovation of Queensland University of Technology, Australia. TBW, FFM, and fat mass (FM) were determined using the equation proposed by the IAEA.[14] The hydration coefficient for adults (0.732), based on the classic work of Pace and Rathburn[14,20] was applied.

Statistical analysis

Participants were divided randomly into development and cross-validation groups of the same size (n=146). Outliers from anthropometric measurements and %BF ≥3.3 SD were removed from each group. Independent *t*-test was used to detect possible differences in age and physical characteristics between the development and validation groups. Stepwise multiple regression analyses were performed to predict %BF via various models using %BF as a dependent variable and anthropometric variables as independent variables. Different sets of anthropometric variables (individual skinfold sites, sum of four skinfolds [biceps, triceps, subscapular, iliac crest], sum of eight skinfolds, girth and breadth measures [girths at arm relaxed, arm flexed and tensed, minimum waist, gluteal, and maximum calf; breadths at biacromial, biiliocristal, humerus, and femur] and anthropometric index [BMI, WHR, WSR, and acromio-iliac index]) were entered as independent variables along with age, body weight, and stature. The coefficient of correlation (r), coefficient of determination (r^2), standard error of the estimate (SEE), and the Akaike Information Criterion (AIC) were presented to evaluate the precision of the equations. Equations that have a high r^2, a small SEE, and the smallest AIC value was chosen for the best "fit" models.

The estimated %BF values using the proposed equations were compared with the values obtained from the reference method using a paired sample *t*-test in the cross-validation groups. The pure error (PE) was calculated as the square root of the mean of squares of differences between measured and predicted body composition. A smaller pure error value indicated greater accuracy of the equation. The proposed equations were also evaluated using scatter plots and Bland and Altman plots.[21] In addition, %BF estimated from existing equations of Durnin and Womersley,[9] Davidson *et al*,[2] and Gurrici *et al*[11] were compared with $\%BF_{D2O}$ using paired-sample *t*-test and the Bland and Altman plots.[21] All statistical analyses were conducted using the SPSS program (version 19, SPSS Inc, 2010, Chicago, IL) and significance was determined at $p<0.05$.

RESULTS

Physical characteristics of the groups are presented in Table 1. There were no significant between-group differences in any physical characteristics. Table 2 shows the proposed prediction equations. The best fit prediction equation was obtained from skinfold variables with r=0.83. Age made a significant contribution to the prediction equation using skinfolds. The proposed equations

Table 1. Characteristics of the study groups

	Development Group (n=146)	Validation Group (n=146)	*p*
Age (years)	39.0 ± 11.6	38.7 ± 12.0	0.824
Body weight (kg)	58.2 ± 10.0	59.5 ± 10.4	0.309
Stature (cm)	165.0 ± 7.0	165.3 ± 5.9	0.735
BMI (kg/m^2)	21.3 ± 3.1	21.6 ± 3.3	0.449
%BF$_{D2O}$	21.1 ± 6.6	21.7 ± 7.5	0.466
Triceps skinfold (mm)	9.7 ± 4.6	10.2 ± 5.1	0.385
Abdominal skinfold (mm)	15.1 ± 8.5	15.6 ± 8.6	0.616
Sum of 4 skinfolds† (mm)	45.0 ± 22.1	48.2 ± 24.5	0.242
Waist girth (cm)	75.0 ± 7.8	76.0 ± 8.8	0.291
Gluteal girth (cm)	89.7 ± 6.5	90.3 ± 6.9	0.414
Humerus girth (cm)	6.9 ± 0.4	6.9 ± 0.4	0.317
WSR	45.5 ± 4.9	45.9 ± 5.3	0.480

Note: † sum of skinfold thicknesses at triceps, biceps, subscapular, and iliac crest; *p*: *p* values

Table 2. Percentage body fat prediction equations developed using anthropometric variables

Dependent variables	Regression equation	*r*	*r*^{2}	SEE	AIC
Skinfold sites	%BF = 8.000 + 0.402 (abdominal) + 0.486 (triceps) + 0.059 (age)	0.831	0.691	3.680	377.2
Sum 4 skinfolds†	%BF = 7.579 + 0.237 (sum of 4 skinfolds) + 0.073 (age)	0.804	0.647	3.919	399.8
BMI	%BF = -6.971 + 1.318 (BMI)	0.631	0.398	5.100	472.5
Girth and breadth measures	%BF = -14.533 + 0.363 (waist girth) + 0.474 (gluteal girth) - 4.955 (humerus breadth)	0.740	0.547	4.455	432.2
Anthropometric index	%BF = -16.849 + 0.553 (WSR) + 0.219 (body weight)	0.680	0.462	4.837	461.3

Note: † sum of skinfold thicknesses at triceps, biceps, subscapular, and iliac crest; *r*: coefficient of correlation; *r*^{2}: coefficient of determination; SEE: standard error of the estimate; AIC: the Akaike Information Criterion

showed the SEE ranged from 3.7 to 5.1%. The BMI equation showed the poorest performance with r, r^2, and SEE values of 0.63, 0.40, and 5.1%, respectively.

The predicted %BF values from the proposed equations were compared with %BF$_{D2O}$ using the cross-validation group (Table 3). The %BF values of the proposed equations were comparable to the %BF$_{D2O}$ with mean difference 0.2-0.5%, PE of 3.7-5.1%, and r between 0.63 and 0.83. The variables included in the prediction equations were responsible for about 40-69% of the variance in the models. The accuracy of each prediction equation was further assessed in the Bland and Altman plots presented in Figure 1 with the widest limits of agreement between -9.2 (lower limit) and 8.7 (upper limit) from the BMI prediction equation. A slight tendency to underestimate %BF was observed in all prediction equations as %BF increased.

Table 4 presents the differences between %BF$_{D2O}$ and selected existing prediction equations. The equation by Durnin and Womersley[9] showed the closest value to the %BF$_{D2O}$ with a slight but significant (p<0.05) underestimation (0.8%), while equation proposed by Davidson *et al* [2] underestimated %BF at about 6.7% in our cross-validation samples (Table 4). Application of the BMI equation by Gurrici *et al* [11] resulted in overestimation by 3.4%. Agreement between the predicted %BF and the reference method as evaluated with the Bland and Altman plots showed limits of agreement (mean difference ± 1.96 SD) between 7.0 and 9.0%.

DISCUSSION

The present study developed and validated %BF prediction equations for Indonesian males. The proposed prediction equations generated from both individual and sum of four skinfolds displayed good precision according to Heyward and Wagner's[14] recommendation (r>0.80 and SEE<4.0%). In addition, cross-validation analysis for these equations indicated very good precision with PE less than 3.0%.

The proposed equations showed comparable accuracy and precision to the equation developed by Gurrici *et al* [11] in 110 Indonesian adults living in Sumatra and was consistent with findings in a previous study by Kagawa and colleagues [4] in 45 Japanese adult males living in Perth. It is possible that the reference technique used to measure %BF would be more precise in estimating %BF than the 2C model the present study and others used.[15,22]

Equations which used an individual skinfold site and the sum of four skinfolds showed the strongest correlation with both equations having r=0.87; r^2=0.76; and SEE= 3.7%. Subscapular, triceps, and abdominal skinfold sites made significant contributions to the model, indicating that fat deposition in participants was predominantly in the upper trunk region. Our findings are similar with those from previous studies that %BF from skinfolds gave the best performance in terms of correlation, bias, and error.[22-24] The inclusion of age as a predictor further improved the skinfold equations as found in previous studies by van der Ploeg *et al* [22] and Kagawa *et al.*[4]

Prediction equations generated from girth and breadth

Table 3. Comparison of %BF from the reference method and anthropometric prediction equations in the cross-validation samples

Measures	Reference††	Prediction equation			Paired test		Limits of agreement
	Mean ± SD	Mean ± SD	Bias ± SD	PE ± SD	*r*	*t*	
Skinfold sites	21.3 ± 7.1	21.5 ± 5.5	-0.2 ± 3.8	2.8 ± 2.6	0.841**	-0.478	-7.7 – 7.4
Sum of 4 skf†	21.4 ± 7.2	21.9 ± 5.9	-0.5 ± 3.7	2.8 ± 2.4	0.858**	-1.658	-7.7 – 6.7
BMI	21.3 ± 6.9	21.5 ± 4.3	-0.3 ± 4.6	3.6 ± 2.8	0.768**	-0.683	-9.2 – 8.7
Girth & breadth measures	21.6 ± 7.3	21.7 ± 5.6	-0.2 ± 4.2	3.2 ± 2.8	0.818**	-0.448	-8.5 – 8.2
Anthropometric index	21.4 ± 7.2	21.6 ± 4.9	-0.2 ± 4.3	3.3 ± 2.8	0.805**	-0.575	-8.7 – 8.3

Note:* $p<0.05$; ** $p<0.01$; †: sum of skinfold thicknesses at triceps, biceps, subscapular, and iliac crest; ††: the reference values are different from each variable due to the different dropped outliers; *r*: coefficient of correlation; *t*: *t* values

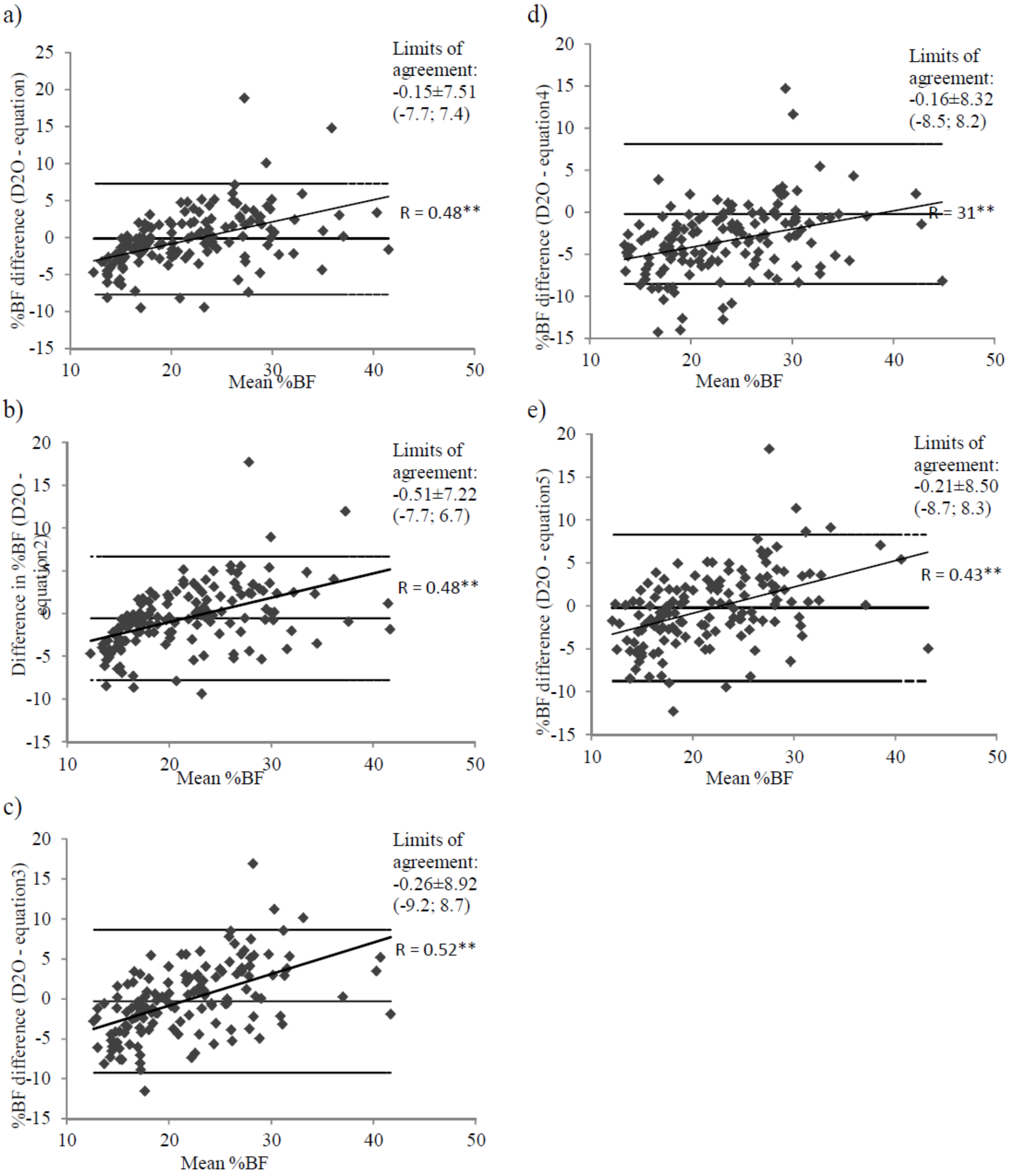

Figure 1. Agreement between measured %BF and %BF estimated using prediction equations based the analysis of Bland and Altman technique. The difference between %BF obtained from D_2O and %BF predicted from skinfold site (a), sum of four skinfold (b), BMI (c), girth and breadth measures (d), and anthropometric index (e) prediction equations is plotted against mean %BF. Note: equation 1: %BF = 8.000 + 0.402 (abdominal) + 0.486 (triceps) + 0.059 (age); 2: %BF = 7.579 + 0.237 (sum of 4 skinfolds) + 0.073 (age); 3: %BF = -6.971 + 1.318 (BMI); 4: %BF = -14.533 + 0.363 (waist girth) + 0.474 (gluteal girth) - 4.955 (humerus breadth); 5: %BF = -16.849 + 0.553 (WSR) + 0.219 (body weight); R: the coefficient of correlation of the trend line; ** $p<0.01$

Table 4. Differences between %BF obtained from D_2O and various prediction equations

	Mean ± SD	Paired correlation	Paired difference	Limits of agreement
		r	Mean diff ± SD	
%BF from D_2O	21.7 ± 7.5			
%BF from DW	20.9 ± 7.1	0.86**	0.8 ± 3.9*	7.7 (-6.9 – 8.5)
%BF from D	15.0 ± 6.3	0.88**	6.7 ± 3.6**	7.0 (-0.3 – 13.7)
%BF from Gurrici	25.1 ± 4.9	0.81**	-3.4 ± 4.6**	9.0 (-12.3 – 5.6)

Note: * $p<0.05$; ** $p<0.01$; *r*: coefficient of correlation; DW: %BF predicted using BD formula of Durnin and Womersley (1974) and %BF formula of Siri (1962); D: %BF predicted using formula of Davidson et al. (2011); Gurrici: %BF predicted using formula of Gurrici et al. (1998)

measures and anthropometric indices indicated fairly good in the development group, however evaluation in the cross-validation group showed good precision with PE less than 3.5%. Whereas, the prediction equation using BMI was poor in the development group but fairly good in the cross-validation analysis. Even though waist girth, gluteal girth, and WHR may be useful to evaluate fat distribution,[25] race and gender gave significant differences in the distribution of visceral adipose tissue in relation to those measures.[26] Moreover, Lei *et al*[27] considered that those measures are highly related and therefore it is hard to be modelled in multiple regression analysis. BMI is the most commonly used tool for evaluating excessive body weight and the use of BMI to determine %BF is criticized because of the quadratic relation and the variability in the association between BMI and %BF resulted in a significant error in the prediction of %BF using BMI regression equation.[28]

A cross-validation study of the new prediction equations indicated high correlation with the measured %BF, however, a slight tendency to overestimate %BF at a lower %BF and a tendency to underestimate %BF at a higher %BF. The most prominent deviation was observed in the BMI equation as reported in other studies.[10,11,23,29] Deurenberg *et al*[23] suggested that the bias of prediction equations was related to level of body fatness with underestimation at higher levels of body fatness. Incorrect assumptions can partly explain this phenomenon, for example, the relative contribution of the increased fat mass to body weight becomes greater with increased BMI, whilst the prediction of %BF from BMI assumes that it is constant. Similarly, the skinfold equation assumes that the subcutaneous fat is representative of total body fat, whereas, with the increase in total body fat, the relative amount of internal fat increases, leading to an underestimation of %BF at higher levels of fatness.[23]

Application of prediction equations developed from Caucasians were inappropriate in our samples, particularly the equation by Davidson *et al.*[2] The Durnin and Womersley[9] equation showed a significant underestimation of %BF, but was closer to the measured %BF with a 0.8% bias. This finding confirms the results of previous studies by Küpper *et al*[10] and Gurrici *et al*[11] in Indonesian adults with differences potentially due to race or ethnicity.[12,30,31] A meta-analysis of %BF associated with BMI in Asian populations indicated a different relationship among Asians living in different countries.[32] Even among Indonesian populations, different relationships have been reported between those of Malay and Chinese ancestry.[12] In addition, Durnin and Womersley's prediction equations were developed for the estimation of body density. The conversion from body density to %BF may have resulted in an error in the prediction of %BF. Variability in activity levels,[33] body build,[34,35] muscularity,[32,33] and frame size may also contribute to these differences.[36] The BMI equation by Gurrici *et al*[11] overestimated %BF by 3.4% in the current investigation. This result may partly due to differences in methodology, including sample characteristics.

The present study has several limitations. Participants in the current study were not completely representative of the total Indonesian population due to the heterogeneity of the population. However, participants were chosen from a major ethnic group (ie Javanese ethnicity) and the semi-stratified sampling used enriched the variability of the sample. The use of a two-compartment model for the estimation of FFM also limits the accuracy of the FFM estimation and the use of a multi-compartment approach would have enabled an independent assessment of the various components of FFM.[15,29,37] However, the deuterium dilution technique was the most suitable approach for use in a large free-living sample. In addition, other studies have indicated that the validity of the deuterium dilution technique in body fat estimation is comparable with multi-compartment models.[15] Future studies are recommended to include multiple ethnic groups to develop general prediction equations which are representative of the entire Indonesian population and also use a multi-compartment model as the reference for body composition.

In conclusion, our findings highlighted that earlier anthropometric prediction equations (ie prediction equations of Durnin and Womersley,[9] Davidson *et al*,[2] and Gurrici *et al*[11]) are inappropriate when applied to participants in the current study. The prediction equations developed in the study can accurately predict %BF. The significance of this finding is equations were developed using a criterion method of body composition assessment and cross-validated with large samples across a wide age range (18-65 years).

ACKNOWLEDGEMENTS

The current study was supported by the Directorate General of Higher Education Republic of Indonesia, Gadjah Mada University, Indonesia, and Queensland University of Technology, Australia. We are grateful to the participants in the current study and the data collection staff. For the laboratory assessment we would like to thank Ms Connie Wishart.

AUTHOR DISCLOSURES

The authors report no conflict of interests.

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Original Article

Development and validation of anthropometric prediction equations for estimation of body fat in Indonesian men

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對印尼男性體脂肪估計之體位預測方程式的發展和驗證

利用氧化氘稀釋法測量 292 位，年齡 18-65 歲男性之體組成。將所有參與者分成發展組(146 位)和交叉驗證組(146 位)，測量其身高、體重、8 處皮脂厚度、5 處圍長以及 4 處骨寬，並計算身體質量指數、腰臀比和腰圍身高比。利用多元迴歸分析，將皮脂厚度、骨寬、圍長、身體質量指數及其他指標當做自變項，由氧化氘稀釋法測得的體脂肪百分比(%BF)當參考值，來發展方程式。所有方程式皆用交叉驗證組的指標數值進行驗證。由參考方法得到的結果亦和 3 個現有的預測方程式-Durnin 和 Womersley (1974)、Davidson 等(2011)和 Gurrici 等(1998)進行比較。本研究所提出的預測方程式經交叉驗證樣本證明為有效，相關系數 0.77- 0.86、偏差 0.2-0.5%、純誤差 2.8-3.6%。由皮脂厚度產生之方程式預測能力最佳，相關系數 0.83、估計標準誤 3.7%、赤池信息量準則 377.2。Durnin 和 Womersley (1974)、Davidson 等(2011) 2 個方程式皆顯著低估(p<0.001)體脂肪百分比分別達 1.0 和 6.9%；而 Gurrici 等(1998)的方程式則顯著高估(p<0.001)體脂肪百分比達 3.3%。以上結果顯示，本研究提出的預測方程式對於印尼男性體脂肪百分比的預測是可行的。

關鍵字：體位測量、預測方程式、氧化氘稀釋、體脂肪、印尼