Validation of Bioelectric Impedance Analysis for the Assessment of Body Composition in Young Adult Thai Women

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Abstract

Obesity imposes high risks of metabolic diseases that become a major health concern in many countries. An accurate assessment of body composition is, therefore, required in the evaluation of body fatness of the population and hence in preventing the diseases. Bioelectric impedance analysis (BIA) has great potential in the assessment of body composition of population in field studies. However, BIA is sex, age, and ethnic specific. Currently, a prediction equation for Thais is still not available. In addition, the influences of alterations in body fluids during menstrual cycle in women on BIA are in controversy. This study attempted to establish a BIA equation for young adult Thai women (age 18-29 years) using the body density determined by an underwater weighing as a criterion method, and to re-evaluate the effect of menstruation on BIA. Results showed that BIA values were not significantly changed in different phases of menstrual cycle. For the women with percentage body fat (%BF) less than 30%, Lohman's equation for BIA of the women at the same age range was acceptable. On the other hand, body weight and resistance were the main attributes of BIA for overweight and obese women with %BF greater than 30%. A prediction BIA equation for this population is fat-free mass = 0.61 body weight - 0.003 resistance + 0.66. The coefficient of correlation (r), multiple regression (R^2), and standard error of estimate (SEE) are, respectively, 0.98, 0.97, and 0.92.

J Physiol Biomed Sci. 2013; 26(2): 69-75

Keywords: *Bioelectric impedance analysis, BIA, body composition, menstrual cycle, prediction equation, Thai women*

There is an increasing incidence of metabolic diseases in the world population. Among several factors, excess body fatness has been ascribed as a major cause of the metabolic syndrome which includes diabetic mellitus, dyslipidemia, hypertension, and coronary heart diseases.[1] Self awareness and/or continual monitoring of body composition with respect to body fatness are, therefore, essential in preventing the diseases. Currently, there are several methods for assessing body composition available for laboratory and field uses such as densitometry, dual energy x-ray absorptiometry (DXA), magnetic resonance imaging (MRI), bioelectric impedance analysis (BIA), and skinfold thickness. However, densitometry, DXA and MRI are expensive, require technical skills, and are not portable for field work, whereas BIA and skinfold method are less expensive, need less technical skill, and are portable.[2] The latter two are, therefore, commonly used in field studies. Recently, BIA-based instruments are commercially available and gain popularity for fitness center and home uses. The principle of BIA is based on the impedance of body to alternating current flow, which, in turn, depends on body composition. There are many empirical equations for the estimation of total body water (TBW), fat mass (FM), and fat-free mass (FFM) based on sex, age, weight, height, and race. These prediction equations are, however, generally population specific and can be used with good accuracy only with the population of the same characteristics as the reference population.[3-5] The reliability and validity of different equations for African American, Asian and Indian American have been evaluated and the conclusion was made that the generalized equation for BIA cannot be applied for different ethnic groups.[6] Furthermore, disparities among different ethnic groups are extended to the Asian population. Thus, validity in the estimation of percentage body fat (BF) using skinfold thickness or BIA has been questioned in Singaporeans (among Chinese, Malay, and Indian descendants).[7] Ethnic variances in the assessment of BF could be explained largely by differences in BF distribution and body frame size.[3] At present, a prediction equation for the assessment of BF specifically for Thai population is lacking. Previous studies in Thai subjects using equations established for other ethnic population must, therefore, be interpreted with caution.

In addition to individual physical characteristics, several factors have been shown to influence BIA measurements, such as food and/or beverage consumptions, exercise, medical conditions, and

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environment.[5] It has been shown that, in women, body fluid and electrolyte varies during menstrual cycle as a result of cyclic changes in sex hormones,[8] changes in body temperature and skin blood flow.[9,10] These physiological factors would affect BIA measurements. However, reports on the influence of menstrual cycle on BIA are in controversy. Thus, Chumlea and colleagues,[11] Gualdi-Russo and Toselli,[12] and D'Alonzo et al.[13] failed to observe any changes in BIA during menstrual cycle whereas Deurenberg *et al.*[14] reported significant differences in body impedance one week prior to and one week after menstruation. Gleichauf and Roe also found an increase in resistance during the menstrual phase.[15] Based on ethnic specificity of BIA, the question on the influence of menstruation in women is still unresolved.

The present study aimed to develop a prediction equation for BIA specifically for young adult Thai women and to determine the effect of menstrual cycle on the assessment of BF using BIA.

Materials and Methods

Subjects

One hundred and sixty-one sedentary women, aged between 18-29 years were recruited by advertisement. All volunteers were in good health according to medical history and physical examinations, showed no signs of edema nor dehydration, and were not on drugs that could affect water and electrolyte homeostasis. Of these, 21 women who had regular menstrual period and had %BF between 15-30% were assigned for the study on the effect of menstrual cycle on BIA. In this experiment, the cycle was divided into menses, follicular, postovulatory, and premenstrual phases, which were determined from a questionnaire given to each subject. During the study period, these subjects did not take any contraceptives. All subjects signed informed consent and the protocol was approved by Mahidol University Institutional Review Board. The number of volunteers recruited was based on the primary objective to assess correlation in %BF and %FFM measured by BIA manufacturer's equation and by Lohman's equation. With the estimated correlation coefficient of 0.65 and using a 2-sided type I error of 0.01 and 85% power, a sample of 158 was required to test the null hypothesis of 0.45 against alternative hypothesis of 0.65. This study, therefore, included 161 subjects in the main study group in which 21 women were assigned for studying the effect of menstruation on BIA.

Anthropometric measurements

Body weights were measured using a beam balance to ± 0.1 kg (Weylux model 424J, UK). In 21 subjects, who enrolled in the study of menstrual cycle, the body weights were measured daily for one cycle (28 days). Body heights were measured at mid inspiration phase with a stadiometer to ± 0.01 m.

Body density

Body density was measured by underwater weighing (UWW) to the nearest 10 g, and corrected for residual lung volume determined by the nitrogen washout method using a computerized spirometer (Vmax 299, Sensormedics, Yorba Linda, CA, USA). Body density was calculated from the formula of Buskirk et al.[16] assuming gastrointestinal volume of 100 ml. Siri's equation was used to assess BF and FFM (FFM_{uww}).[17]

$$D_b = W_a / [\{(W_a - W_w)/D_w\} - \{RV + GI\}];$$

where D_b = body density (kg/L),
Wa = weight in air (kg),
W_w = weight in water (kg),
D_w = density of water (kg/L),
RV = residual lung volume (L),
GI = gastrointestinal volume (L).

Bioelectric impedance analysis

Bioelectric resistance and reactance were measured using BIA-101 impedance analyzer (RJL system, Detroit, MI) to ± 1 ohm. Injecting current of 800 µA at a single frequency of 50 Hz was applied through the inductive electrodes attached to the dorsum of right hand at the third metacarpophalangeal joint and right foot just proximal to the second metatarso-phalangeal joint. The detection electrodes were placed over the dorsum of right hand midway between the distal prominence of the radial and ulna styroids and the right foot midway between the malleoli on the anterior surface of ankle. Resistance (R) and reactance (X_c) were recorded 3 times for each subject to the nearest ohm and the lowest value was used in the calculation. The bioelectric impedance analyzer was calibrated daily against precision resistors (500, 680, and 1000 ohms) provided by the manufacturer. Prior to the measurement of bioelectric resistance and reactance, subjects had emptied their bladder and fast overnight. Fat-free mass (FFM) was calculated from the equation provided by the manufacturer and from the prediction equation of Lohman.[18]

$$FFM = 0.475\,(Ht^2/R) + 0.295\,(Wt) + 5.49;$$

where FFM = fat-free mass (kg),
Ht = body height (cm),
R = resistance (ohm),
Wt = body weight (kg).

Statistical analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS for Windows, version 17). Differences in the mean R, X_c, and Wt in various phases of menstrual cycle were tested by repeated measures one-way ANOVA. A prediction formula for FFM derived from BIA (FFM_{BIA}) was developed using stepwise multiple regression. Student's *t*-test was used to compare the means and SDs of the criterion FFM_{uww} and predicted FFM_{BIA}. Statistical significance was set at $P < 0.05$.

Results

General characteristics of subjects

Subjects in the main group had mean ± SD age of 23 ± 3 years (range 18-29), which was not different from those in the subgroup of 21 women (Table 1). In addition, the anthropometric characteristics were similar in both groups.

Reliability of bioelectric impedance measurements

In order to determine the reliability of the BIA, resistance was repeatedly measured with 3 different resistors of known values over a 10-day period in 10 subjects, daily for 7 days. Table 2 shows the precision and variability (coefficient of variation) of the measurements. It is apparent that mean resistance values for the resistors were very close to the standard values (0.3-0.6% error) for each resistor and did not vary more than 5 ohms during the test period. On the other hand, the variability of the repeated measures on the subjects, who were randomly selected from volunteers in the main group, was greater than that observed with the standard resistors. However, the variability of the measurements in subjects, calculated as the coefficient of variation, ranged from 1.53% to 3.64%.

Influence of menstrual cycle on BIA

Since the influence of menstrual cycle on BIA is still in controversy, we first determined body weights and BIA of 21 subjects who had regular menstrual period. Daily assessment for one menstrual cycle (28 days) showed that neither resistance nor reactance in all four phases was altered. Besides, body weights remained unchanged throughout (Table 3). The data indicate that BIA is not affected by menstrual cycle in our subjects.

Percentage of body fat and fat-free mass obtained from BIA

We then determined %BF and FFM of the main group (161 subjects) using BIA and the equation provided by the manufacturer. The mean ± SD of R, X_c, %BF, and FFM were 640 ± 72.1 ohm, 72 ± 8.9 ohm, 24.7 ± 3.8%, and 39.3 ± 0.05 kg, respectively (Table 4).

Validation of prediction equation

In order to validate a prediction equation, body composition of the subjects must be determined by a criterion method for comparison. In this study, we used body density (D_b) derived from underwater weighing (UWW) and Siri's equation.[17] According to Buskirk's equation (1961),[16] residual lung volume (RV) and gastrointestinal volume are required for the calculation of D_b from UWW. In view of the lack of RV values for Thais, we decided to measure RV in our subjects by the nitrogen washout technique using Sensormedic Vmax 299, but assumed a gastro-intestinal volume of 100 ml. RV of young adult Thai women ranged from 0.71 L to 1.71 L with mean ± SD of 1.18 ± 0.02 L, which was significantly less ($P < 0.05$) than the value calculated from the European study, 1.21 ± 0.02 L.[19] The body composition obtained from UWW method is shown in Table 4. As shown in Table 4, although %BF derived from BIA using the manufacturer's equation and UWW was not different, FFM calculated from BIA was significantly higher ($P < 0.05$) than that obtained from the criterion method, indicating that BIA's equation is not suitable for the measurement of FFM in Thai women.

On the other hand, when we used Lohman's

Table 1 Physical characteristics of subjects participating in the menstrual cycle study (Subgroup) and in the validation study (Main Group)

Characteristics	Subgroup (n = 21)	Main group (n = 161)
Age (year)	22.9 ± 2.8 (19-28)	23.4 ± 3.0 (18-29)
Wt (kg)	51.0 ± 7.2 (41-72)	52.0 ± 9.1 (37.6-87.3)
Ht (cm)	158 ± 5.1 (150-167)	155.4 ± 4.8 (144.1-167.1)
BMI (kg/m^2)	20.5 ± 2.4 (16.9-27)	21.5 ± 3.4 (16.2-33.4)
FFM (kg)	39.0 ± 3.9 (33.5-50.4)	39.0 ± 4.7 (31.3-53.9)
%Fat	23.5 ± 6.0 (15-30)	24.3 ± 4.9 (14.4-38.2)

Values are mean ± SD (range); Wt = weight; Ht = height; BMI = body mass index; FFM = fat-free mass by BIA using Lohman equation; %Fat = FFM subtracted from body weight.

Table 2 Reliability of resistance measurements using standard resistors and in volunteers.

	Mean ± SD	%CV	%error
Resistor (ohms) (n = 20)			
560	558 ± 0.8	0.14	0.36
680	676 ± 1.2	0.18	0.59
1000	1003 ± 0.7	0.07	0.30
Subjects (n = 7)			
1	701.9 ± 14.7	2.09	
2	748.1 ± 27.2	3.64	
3	835.3 ± 20.9	2.50	
4	644.6 ± 19.4	3.01	
5	677.1 ± 15.9	2.35	
6	685.0 ± 10.5	1.53	
7	675.4 ± 21.2	3.13	
8	611.0 ± 15.8	2.57	
9	553.9 ± 11.9	2.13	
10	761.6 ± 26.1	3.43	

n = number of measurements (measurements in subjects were made daily for 7 days); SD = standard deviation; %CV = percent coefficient of variation (SD/mean x 100).

Table 3 Body weight and impedance in different phases of menstrual cycle

Menstrual cycle	Wt (kg)	R (ohm)	X_c (ohm)
Phase 1	51.1 ± 7.1	667 ± 79	70 ± 9
Phase 2	51.0 ± 7.2	669 ± 73	70 ± 8
Phase 3	51.0 ± 7.2	663 ± 78	70 ± 8
Phase 4	51.1 ± 7.2	666 ± 73	70 ± 8

Values are mean ± SD (n = 21); Phase 1 = menses; Phase 2 = follicular phase; Phase 3 = postovulatory phase; Phase 4 = premenstrual phase; Wt = body weight; R = resistance; X_c = reactance.

Table 4 Percentage of BF and FFM calculated from BIA manufacturer's equation, Lohman's equation, and from underwater weighing method

	BIA manufacturer	Lohman	UUW
R	640 ± 72.1 (447-819)	640 ± 72.1 (447-819)	-
X_c	72 ± 8.9 (52-94)	72 ± 8.9 (52-94)	-
D_b	-	-	1.04 ± 0.01 (1.02-1.06)
%BF	24.7 ± 3.8 (16-43)	24.3 ± 4.9 (16.0-36.1)	24.7 ± 3.8 (15.8-34.4)
FFM	39.3 ± 0.05* (31.1-50.7)	39.0 ± 4.7 (31.3-53.9)	38.9 ± 5.0 (30.3-58.3)

UWW = underwater weighing; R= resistance in ohms; X_c = reactance in ohms; D_b = body density calculated from Siri equation; %BF = % body fat; FFM = fat-free mass; values are mean ± SD (range) from 161 subjects. * $P < 0.05$ compared to UWW method (Student's paired *t*-test).

Table 5 Physical characteristics of normal and overweight subjects participating in the validation of Lohman equation

Characteristics	Normal (n = 141)	Overweight (n = 20)
Age (year)	23.3 ± 3.1 (18-29)	24.1 ± 2.8 (19.8-29)
Wt (kg)	49.6 ± 6.1* (37.6-72.3)	69.0 ± 8.1* (58.1-87.3)
Ht (cm)	155.3 ± 4.8 (144.3-166.9)	155.9 ± 5.3 (144.1-167.1)
BMI (kg/m^2)	20.5 ± 2.1* (16.2-27.2)	28.3 ± 2.4* (25.9-33.4)
%BF-Siri	23.69 ± 3.3* (15.84-29.62)	31.41 ± 1.46* (30.17-34.44)
R (ohm)	651 ± 67* (525-819)	558 ± 53* (447-665)
X_c (ohm)	72 ± 9.0* (54-94)	66 ± 70* (52-78)
RI (cm^2/ohm)	37.5 ± 4.5* (28.7-47.4)	44.0 ± 5.2* (35.0-54.3)

Values are mean ± SD (range); Wt = Weight; Ht = Height; BMI = Body mass index; %BF-Siri = percent body fat from body density using Siri equation; R = resistance; X_c = Reactance; RI = resistance index (Ht^2/R). *$P < 0.05$ (unpaired *t*-test) compared between normal and overweight subjects.

equation for BIA to calculate our subjects' body composition,[18] FFM was 39.0 ± 4.7 kg (mean ± SD), which was not significantly different from the value obtained from UWW. The data suggest that BIA may be used to estimate FFM in young adult Thai women provided that Lohman's equation is used instead of that recommended by the manufacturer.

Validation of FFM from Lohman's equation

Since Lohman's equation appears to be suitable for estimating FFM, validation of this equation against the criterion method (UWW) was performed. Figure 1a illustrates the relationship between FFM obtained from BIA using Lohman's equation and that derived from UWW and Siri's equation. The regression analysis showed strong correlation coefficient (r = 0.93) and high multiple regression (R^2 = 0.87), but low standard error of estimate (SEE = 1.89). However, when %BF was plotted instead (Figure 1b),

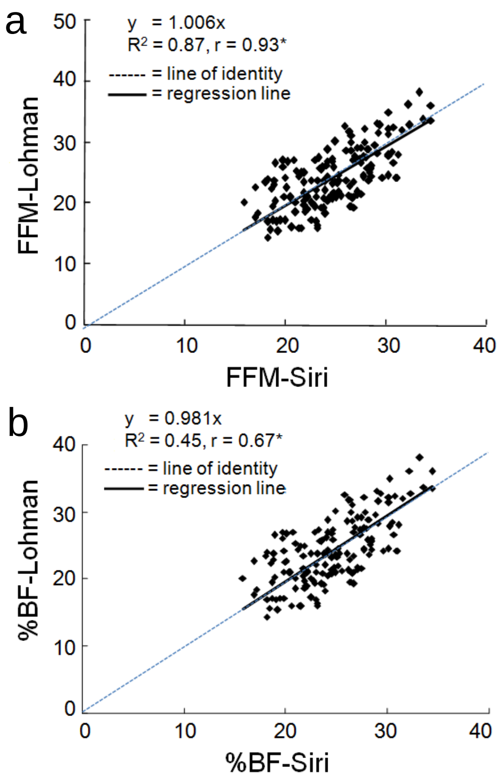

Figure 1 Correlations of FFM (a) between the values obtained from UWW (Siri) and from BIA (Lohman), and % BF; (b) between the values obtained from UWW (Siri) and from BIA (Lohman). R^2 = regression coefficient, r = correlation coefficient, * $P < 0.05$.

the correlation was significantly decreased (r = 0.67, R^2 = 0.45). In addition, Lohman's equation yielded higher values at %BF greater than 30%, suggesting that this equation is not appropriate for estimating %BF in Thai women. Based on this finding, we then divided the subjects into two groups. Those who had %BF < 30% was considered normal (n = 141), and those with %BF > 30% was overweight subjects (n = 20). The physical characteristics of these subjects are shown in Table 5. Percentage BF and FFM were again calculated in these two groups using different equations and the data were illustrated in Figure 2. Results showed that, in normal subjects, both Lohman's equation and BIA equation underestimated %BF compared to the criterion method (Figure 2a), but only the BIA equation overestimated FFM (Figure 2b). In contrast, both equations overestimated %BF (Figure 2c), whereas they underestimated FFM in overweight women (Figure 2d). These data indicate that both equations are not valid for estimating body composition in overweight and obese Thai women. However, multiple regression analysis of FFM obtained from UWW and BIA using Lohman's equation in normal women revealed a lower SEE compared to that obtained from the group including overweight women. Table 6 illustrates regression equations of FFM before and after grouping. It is seen that Lohman's equation for BIA is best for normal subjects but an adjustment for overweight and obese individuals, in which weight and resistance are predominant variables, is required. The prediction equation for this group of subject is FFM = 0.61 Wt – 0.003R + 0.66.

Discussion

In view of an increased incidence in obesity and metabolic diseases, an assessment of body composition is required for monitoring fatness of the body. BIA is, among others, the most popular field method and widely used in fitness centers and clinics. However, validity of this method depends largely on subject characteristics.[5] This study is the first attempt to establish a BIA equation for the assessment of body composition in young adult Thai women. We found that FFM derived from the manufacturer's equation was higher than the criterion method (UWW). On the other hand, it is acceptable when the Lohman's equation is used. The validity of Lohman's equation is increased when it is applied to non-obese women. A prediction equation for the measurement of FFM using BIA in overweight and obese women is proposed.

Currently, it becomes clear that the relationship between BMI and %BF are different in different ethnicity and even within Asian population.[3] Thus, Indonesians of Malays and Chinese ancestry have different %BF at the same BMI. Similarly, Chinese, Malays and Indian Singaporeans of the same age, sex and BMI all differ in %BF. All Asian population has a considerably higher %BF than the Caucasian of the same age, gender and BMI. In addition, a meta-analysis of Asian ethnic groups revealed differences in %BF among Chinese, Malays Indonesians and Thais.[20] Therefore, ethnic specificity has great impact on the assessment of body composition. Until now, there has been no prediction equation for body composition of the Thai population including no validation on the published equations. This study is the first attempt to establish and to validate BIA equations for the Thais. We selected young adult women in this report for several reasons. Firstly, they are the target group in preventive medicine. Secondly, their health awareness, especially obesity, is high. Thirdly, whether menstrual cycle affect BIA is still unresolved. Fourthly, a BIA equation for subjects of similar characteristics is available for validation. Our study showed that menstruation, although theoretically would influence BIA, had no significant effect on resistance nor reactance. This confirms previous reports by Chumlea and colleagues,[11] Gualdi-Russo and Toselli,[12] and D'Alonzo *et al.*,[13] but it is in contrast with those shown by Gleichauf and Roe and Deurenberg *et al.*[14,15] In the present study, prior to the impedance measurements, subjects refrained from meals, drinks, and exercise, which would affect the measurements. It is noteworthy that the body weights of our subjects were not changed throughout the menstruation cycle whereas changes in resistance were associated with alterations in body weight and FFM in Gleichauf and Roe's study.[15] In addition, Deurenberg and colleagues found only small changes (8 ± 9 ohms) in body impedance during menstrual cycle.[14] Therefore, it is concluded that different phases of menstruation has no significant effect on BIA in young adult Thai women.

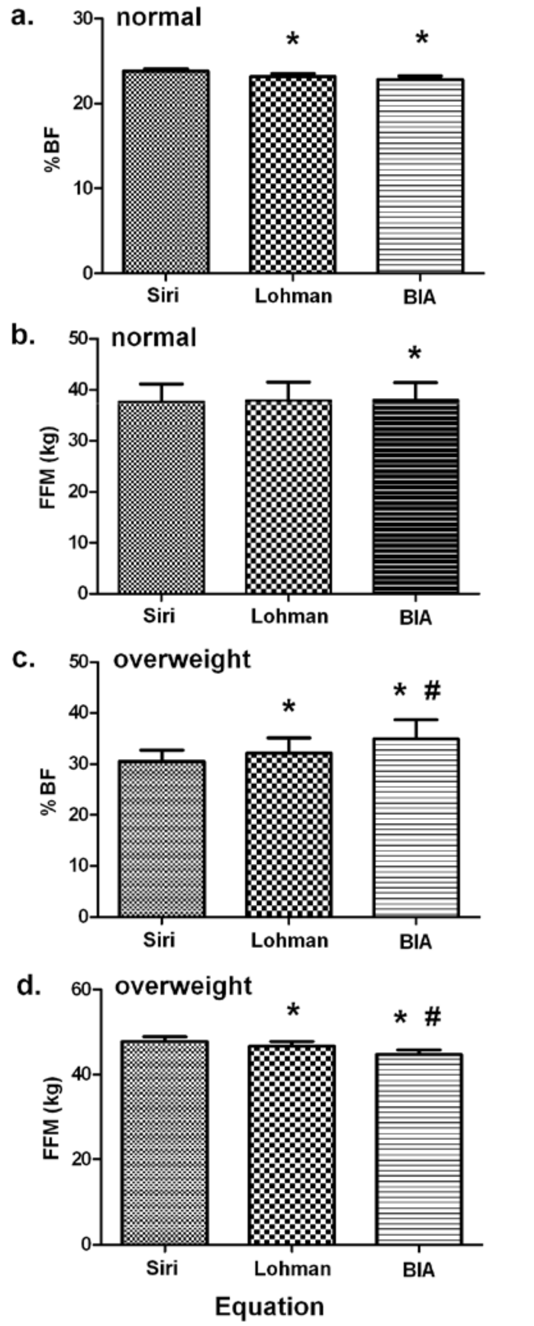

Figure 2 Comparison of body composition in normal (a, b) and in overweight subjects (c, d) obtained from different equations. Values are mean ± SD (n = 141 normal, and 20 overweight). * *P* < 0.05 compared to Siri's equation, # *P* < 0.05 compared to Lohman's equation.

The criterion method used in this study is UWW, which is considered as a "gold standard" method.[21] In addition, RV of each subject was determined by the

Table 6 Regression equations of FFM from BIA in adult women before and after grouping

Group (n)	Equation	r	R^2	SEE
All subjects (161)	FFM from BIA-Lohman*	0.93	0.87	1.89
Normal (141)	FFM from BIA-Lohman*	0.89	0.79	1.83
Overweight (20)	FFM = 0.61 Wt - 0.003R + 0.66	0.98	0.97	0.92

*FFM = 0.475(Ht^2/R) + 0.295 Wt + 5.49; FFM = fat-free mass (kg); Ht = height (cm); Wt = body weight (kg); R = resistance (ohm); r = correlation coefficient; R^2 = multiple regression; SEE = standard error of estimate.

nitrogen washout technique rather than applying the assumed value. In fact, we found that our subjects had less RV than that estimated from the Caucasian's equation.[19] This finding suggests that a specific equation for estimating RV in Thais is needed. FFM obtained from the equation provided by BIA manufacturer was significantly higher than that determined by the criterion method (Table 4). On the other hand, when Lohman's equation was used to calculate FFM, the value was not different from that derived from UWW, suggesting that Lohman's equation may be used for FFM in young adult Thai women. However, when %BF was considered, the value obtained from Lohman's equation was higher than that calculated from UWW at %BF greater than 30%. The results indicate that Lohman's equation is valid only for the individuals who have %BF less than 30%. In the group of subjects whose BF were more than 30%, body weight and resistance appear to play a major role in determining FFM measured by BIA. The prediction equation for these subjects is FFM = 0.61 Wt - 0.003R + 0.66. However, the proposed equation needs further adjustments and validations. It should also be pointed out that the UWW method is based on the two-component model in which other components besides fat and fat-free mass are assumed constant. Validation against the multi-component model such as DXA warrants further studies.

Conclusion

The present study has shown, by validation against UWW method, that Lohman's equation for BIA is applicable for the estimation of body composition of young adult Thai women with normal weight. On the other hand, body weight and resistance are the major variables for the prediction equation of the overweight and obese women. Menstrual cycle has no statistically significant effect in BIA variables.

Acknowledgement

We thank the Institution of Nutrition and the College of Sports Science and Technology, Mahidol University for the uses of densitometry and computerized spirometer.

Conflict of Interest

None.

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