Multicompartment Model Comparison of Body Fat Assessment in Thai Adolescents

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Objective: *To examine the limits of agreement of percent body fat (%BF) assessed by different compartment models (2C and 3C compared to 4C).*
Material and Method: *Fifty-one healthy Thai adolescents (25 males and 26 females) aged 16 to 19 years volunteered in the present study. Underwater weighing (UWW) and dual energy X-ray absorptiometry (DEXA) were used for measurement of %BF for 2C and 3C models. UWW was also used for body density, DEXA for bone mineral content and protein content, and deuterium oxide dilution method for total body water (TBW), used in Lohman's equation for 4C model.*
Results: *Body density, total body water, bone mineral density, and fat free mass were significantly higher in males than in females, whereas females had significantly higher fat than males ($p<0.001$). Compared to $\%BF_{4C}$, $\%BF_{UWW}$ did not show significant deviations from the line of identity in males and females ($R^2 = 0.85$ and 0.75 respectively), whereas $\%BF_{DEXA}$ showed significant deviations from the line of identity in females ($R^2 = 0.59$), but not in males ($R^2 = 0.60$). Bland & Altman analysis demonstrated that UWW and DEXA tended to underestimate %BF in leaner adolescents and overestimate %BF in fatter adolescents.*
Conclusion: *Percent body fat using underwater weighing (2C model) may be used interchangeable with the 4C model in both genders. However, DEXA (3C model) can only be used in males and not in females, which require further research. A regression equation to relate 2C and 3C models to 4C was developed to enable a better estimation of percent body fat in Thai adolescents.*

Keywords: *Body fat assessment, 2C model, 3C model, 4C model, Dual energy X-ray absorptiometry (DEXA), Underwater weighing (UWW), Deuterium oxide dilution technique, Thais, adolescents*

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A variety of methods exists for body composition assessment. A 2-compartment (2C) model of body composition consists of fat mass (FM) and fat-free mass (FFM). The FFM contains water, mineral, protein, and some minor additional constitutes, mainly carbohydrate. The assumptions in 2C models are fixed densities of FM and FFM at 0.9007 g/cc and 1.1000 g/cc respectively, and a constant hydration of the FFM of 73.2%[1].

Dual energy X-ray absorptiometry (DEXA), is a 3-compartment (3C) model that quantifies fat, soft lean tissue, and bone mass. It was first used for the assessment of bone mineral density[2] and later it was shown that it could accurately measure whole body composition[3,4]. Since the measurement of DEXA is two dimensional, this might have an effect on the results, especially at the extreme of tissue depth as in obese and at abnormal hydration levels[5].

The more sophisticated 4 compartment (4C) model comprises of body fat (BF), water, protein and mineral. These components can be measured directly with less assumptions (i.e., body water assessment using isotope dilution technique and bone mineral content by DEXA, and body density by underwater weighing (UWW)) and results are less prone to systematic errors. For that reason this model has been used as the criterion method and %BF was calculated using Lohman's equation[6]. Research to compare different compartment models in Thai subjects is scarce. Hence, the objective of this study was to compare %BF derived from UWW and DEXA with %BF as obtained from the 4C model by examining the limit of agreement of the different compartment models. By providing regressing equations linking 2C and 3C methods to the 4C model, better estimations of %FM can be achieved.

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Material and Method

Subjects

Fifty-one Thai apparently healthy students (25 males and 26 females), aged between 16 and 19 years volunteered in the present study. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures were approved by The Committee on Human Rights Related to Human Experimentation, Mahidol University (No. 136/2547). Written informed consents were obtained from the parents.

Body composition assessment

Body weight was measured to the nearest 0.1 kg with a calibrated digital scale (Weylux, Model 424J, Clarkston, England) in shorts and T-shirts without shoes. Height was measured to the nearest 0.1 cm with a stadiometer (Yamakoshi Seisakusho Co., Ltd., Tokyo, Japan) without shoes. Body mass index (BMI, kg/m^2) was calculated as weight divided by height^2.

The underwater weighing (UWW) for 2C

UWW was performed using a load cell 20 kg (ISC Transcale Technology Co., Ltd., North brook, Illinois, USA) hanging on the top of a stainless steel tank that was connected to IBM compatible data processor. The range of water temperature in the present study was 33 to 35°C. Reliability test of underwater weighing measurement was performed in eight subjects. The results of repeated measurements showed an error percentage ranging from 0.02 to 0.56.

The participants wore swimsuit to be weighed in air and then under water in the tank. Weight in water was measured and the average of the three highest trials from 10 weighing was used. A correction for residual lung volume (RV) was calculated using Goldman and Buskirk's equation(7), taking into account an estimated 0.1 litre intestinal gas volume. Body density was obtained from the formula:

$$\text{Body density} = \frac{\text{Weight in air } (W_a)}{\left[\dfrac{\text{Weight in air } (W_a) - \text{Weight in water } (W_w)}{\text{Density of water}}\right] - (RV + 0.1)}$$

%BF was calculated from body density using Siri's equation(8):

% body fat = [(4.95/Db - 4.50)]*100

Dual energy X-ray absorptiometry (DEXA) for 3C

Total bone mineral analysis was performed using dual energy x-ray absorptiometry (GE Lunar model prodigy software version 3.50.176) at Faculty of Medicine, Ramathibodi Hospital, Mahidol University. Participants were scanned in the supine and in rectilinear position following the guidelines by the manufacturer.

Reliability of the DEXA equipment was assessed by phantom scans prior to the measurement. The DEXA scanner was calibrated daily using the manufacture's "standard block" which was bone-simulating substance of known composition and attenuation. Internal laboratory calibration of this instrument has shown its reliability with a coefficient of variation (CV) of 0.08% for bone mineral density (BMD). The coefficient of variation for estimate of %BF was 0.4%.

Deuterium oxide dilution

Total body water (TBW) was determined by deuterium oxide (D_2O) dilution. The participants were asked not to eat or drink anything 12 hours before testing. A saliva sample of about 2 ml was collected prior to the administration of deuterium oxide. A deuterium oxide dose of 0.15 g/kg body weight (99.9 atom percent excess; Campro Scientific, Veenendaal, The Netherlands), was orally administered. After three hours, a second saliva sample was collected. The samples were kept at -20°C before sending for the analysis using Infrared Spectrophotometry (Mattson Genesis series Fourier transform infrared spectrophotometry).

Total body water and %BF were calculated using the following equations:

$$TBW = 0.95 * tracer * 1{,}000/[D_2O]$$

$$\%BF = [(BW - TBW/0.732)/BW] * 100$$

(where tracer was the amount of D_2O given, $[D_2O]$ was deuterium concentration)

The 4 compartment model (4C)

Body density was obtained from the underwater weighing, total body water was from deuterium oxide dilution, and bone mineral content was obtained DEXA. As originally demonstrated by Siri(8), error propagation is improved when using the 4C model.

Percent body fat using Lohman's 4C model equation(6) was calculated as follow:

$$\%BF_{4C} = [(2.747/Db) - 0.714 \times (TBW/BW) + 1.146 \times (BMC/BW) - 2.05] \times 100$$

(where Db is body density, TBW is total body water, BMC is bone mineral content, and BW is body weight).

Table 1. Characteristics of the volunteers

	Male (n = 25)		Female (n = 26)		p-value
	Mean (SD)	Range	Mean (SD)	Range	
Age (year)	17.7 (0.8)	16.2-19.0	16.9 (0.8)	15.4-18.4	0.001
Weight (kg)	58.5 (6.0)	46.9-69.0	49.8 (4.8)	39.5-61.5	<0.001
Height (cm)	170.9 (6.4)	159.5-183.3	159.7 (4.0)	159.7-166.2	<0.001
Body mass index (kg/m^2)	20.0 (1.6)	17.2-23.2	19.5 (1.5)	17.1-23.6	0.235
Body density (kg/l)	1.07 (0.01)	1.05-1.09	1.05 (0.01)	1.04-1.06	<0.001
Total body water (kg)	36.4 (3.6)	28.0-42.8	27.4 (2.2)	21.9-31.7	<0.001
Fat mass (kg)	7.4 (3.8)	3.2-17.6	14.2 (3.2)	8.5-23.8	<0.001
Fat free mass (kg)	49.9 (5.0)	38.3-58.3	37.5 (3.0)	30.0-43.5	<0.001
Bone mineral content (kg)	2.6 (0.4)	1.9-3.2	2.1 (0.3)	1.6-2.8	<0.001

Statistical analysis

Statistical analyses were performed using the SPSS version 20 for Windows program (SPSS, Chicago, IL, USA). The mean values of percent body fat by 4C, 3C and 2C were compared using paired t-test. Linear regression analysis was used to assess agreement and bias between determinations of %BF among different methods. Pearson's correlation coefficients were calculated. Bland & Altman procedure[9] was used for testing agreement between methods and individual bias. The level of significance was set at $p<0.05$.

Results

The descriptive statistics of the volunteers are presented in Table 1. TBW, FFM, and BMC were significantly higher in males than in females, whereas FM was significantly higher in females than males ($p<0.001$). BMI was in the normal range and showed no differences between the genders. Percent BF derived from Lohman's equation ($\%BF_{4C}$), from under water weighing ($\%BF_{UWW}$), and from dual energy X-ray absorptiometry ($\%BF_{DEXA}$) are shown in Table 2. The $\%BF_{UWW}$ in both males and females, as well as $\%BF_{DEXA}$ in males were not significantly different from $\%BF_{4C}$, but $\%BF_{DEXA}$ in females was significantly higher from $\%BF_{4C}$ ($p<0.05$).

The regression for $\%BF_{UWW}$ and $\%BF_{DEXA}$ against $\%BF_{4C}$ technique significantly deviated from the line of identity (Table 3). The slopes were significantly different from 1. Precision of the individual techniques were determined from the model explained variance (R^2) and standard error of estimate (SEE). In this study the UWW technique provided the closest value estimates of %BF which R^2 for $\%BF_{UWW}$ were 85% and 75% by 4C model and SEE's of 1.3% and 1.2% in males and females respectively. The R^2 for $\%BF_{DEXA}$ were 60% and 59% with SEE's of 2.1% and 1.5% in males and females respectively.

The line of identity (slope = 1 and the intercept = 0) demonstrated the agreement with both UWW and DEXA techniques, but body fat percent was underestimated in leaner subjects and overestimated in fatter subjects (Fig. 1).

Table 2. Percent body fat assessment by single technique

	Male (n = 25)		p-value	Female (n = 26)		p-value
	Mean	SD		Mean	SD	
$\%BF_{4C}$	11.7	3.3		21.8	2.3	
$\%BF_{UWW}$	11.8	5.2	0.72	21.0	3.3	0.08
$\%BF_{DEXA}$	12.4	5.6	0.48	28.7	4.1	0.03

BF = body fat; UWW = underwater weighing; DEXA = dual energy X-ray absorptiometry

Table 3. Regression of $\%BF_{UWW}$ and $\%BF_{DEXA}$ against $\%BF_{4C}$ in both genders

Single technique	R	R^2	Intercept (%)	SEE (%)
UWW				
Male	0.92	0.85	4.9±0.6*	1.3
Female	0.87	0.75	9.1±1.5*	1.2
DEXA				
Male	0.78	0.60	6.2±1.0*	2.1
Female	0.77	0.59	9.5±2.1*	1.5

* Intercept significantly different from zero, or slope significantly different from 1.0
R^2 = coefficient of determination; SEE = standard error of estimation

Fig. 2 showed limits of agreement and bias between $\%BF_{4C}$ and $\%BF_{UWW}$ using the Bland and Altman's method technique. For the UWW technique, the upper and lower limits of agreement were 5.4% and -5.2% in males, and 2.7% and -4.2% in females. The mean difference was 0.1% and -0.8% in males and females respectively. For DEXA technique, the upper and lower limits of agreement were 8.1% and -6.8% with the mean difference 0.7% ($p>0.05$) in males, and 12.4% and 1.4% in females with the overestimate at 6.9% ($p<0.05$) respectively.

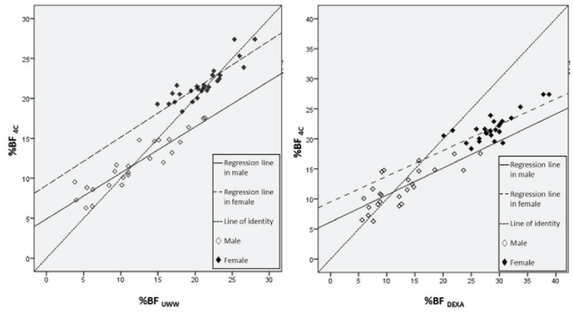

Fig. 1 Regression line of $\%BF_{UWW}$ and $\%BF_{DEXA}$ against $\%BF_{4C}$.

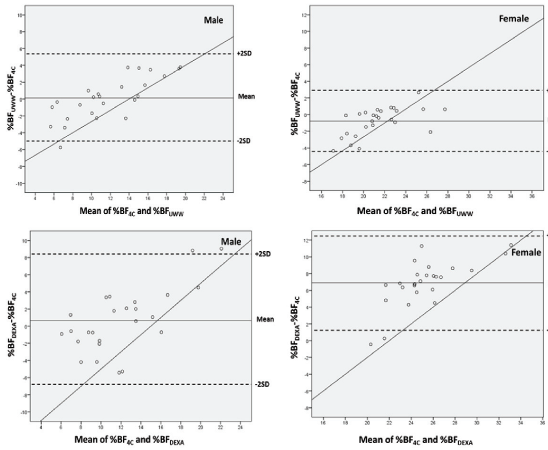

Fig. 2 Bland-Altman plots showing the limits of agreement between $\%BF_{UWW}$, $\%BF_{DEXA}$ and $\%BF_{4C}$.

Discussion

Our data demonstrate that the UWW technique is suitable for the measurement of body fat and gives comparable results compared to the criterion method in Thai adolescent aged 16 to 19 years. Body fat assessed by underwater weighing was not significantly different from $\%BF_{4C}$ model in both males and females. Our results show that the relationship between $\%BF_{4C}$ model and %BF from UWW is explained by the following equations:

for males: $\%BF_{4C} = 0.58*\%BF_{UWW} + 4.9$ ($R^2 = 0.85$, SEE = 1.3)

$\%BF_{4C} = 0.45*\%BF_{DEXA} + 6.2$ ($R^2 = 0.60$, SEE = 2.1)

for females: $\%BF_{4C} = 0.60*\%BF_{UWW} + 9.1$ ($R^2 = 0.75$, SEE = 1.2)

$\%BF_{4C} = 0.43*\%BF_{DEXA} + 9.5$ ($R^2 = 0.59$, SEE = 1.5)

The regression between $\%BF_{UWW}$ using Siri's equation against the 4C model did significantly deviate from the line of identity. The regression lines indicate that only in the range are the lines cross the line of identity $\%BF_{UWW}$ and $\%BF_{DEXA}$ are comparable to $\%BF_{4C}$. For individuals, Bland & Altman plot analysis[9] indicated that %BF was underestimated in leaner volunteers and overestimated in fatter volunteers both in males and females (Fig. 1).

In a larger study reported by Sopher AB et al[11] in 411 children and adolescents, the comparison of body fat was made using 4C and DEXA (Lunar model) like in this study. The authors reported a strong relation between the two methods, which was not affected by gender, age, and BMI. However, in our study only $\%BF_{DEXA}$ was not different from $\%BF_{4C}$ in males, but differed significantly in females. Though our volunteers had a normal nutritional status, their body fat varied widely (8.5-23.8 kg).

Though DEXA is known for its precision and reproducibility[12], it has still questionable validity due to its two-dimensional measurements, especially at the extreme of tissue depth. In addition, the level of FFM hydration level affects the validity of the body fat measurement[13-15].

Compared to 2C models, the 4C model has the advantage that it measures fat with an acceptable accuracy, even though 4C model requires measurements of many variables. Each variable has an inherent measurement error that reflects the precision of the method used to assess it. The total measurement error is a function of the error (degree of precision) associated with measuring each variable in the model (e.g., Db, TBW and BMC for the 4C model). Experts agreed that the error for the combined-methods approach is generally equal to or even lower than the sum of the errors for the individual techniques. Fried et al reported errors of ±1.0 %BF and ±1.1 %BF for the 2C and 4C techniques respectively. Thus, the cumulative measurement error associated with the multiple measurements used to assess the various components of the 4C model does not offset the improved accuracy in estimating %BF. However, several researchers have demonstrated that the individual measurement errors were not substantially additive, and the total error for the 4C model was only 1 %BF[17,18]. Main advantage of the 4 compartment model is that assumptions used in 2 compartment models are avoided, and with that possible systematic errors due to violation of assumptions.

Limitation of the present study is the homogeneous study sample as we recruited only subjects with normal nutrition status, The results are thus applicable only for normal adolescents, and may not be able to apply to the general adolescent population or to specific sub groups.

Conclusion

The present study shows that percent body fat using underwater weighing is interchangeable with %BF from a 4C model in both males and females, but for DEXA this is only true for males, not for females, which require further research. Regression equation to convert results from 2C and 3C models to results of 4C were developed to get better estimates of percent body fat in Thai adolescents.

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Potential conflicts of interest

None.

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การเปรียบเทียบวิธีวัดไขมันร่างกาย ด้วยวิธี multicompartment model ในวัยรุ่นไทย

วีรชาติ ศรีจันทร์, กัลยา กิจบุญชู, อุรุวรรณ แย้มบริสุทธิ์, วิยะดา ทัศนสุวรรณ, Paul Deurenberg

วัตถุประสงค์: *เพื่อทดสอบค่าขอบเขตการยอมรับของการวัดไขมันร่างกายแบบแยกส่วนที่แตกต่างกัน (2C, 3C เปรียบเทียบกับ 4C)*
วัสดุและวิธีการ: *การศึกษาใช้อาสาสมัครวัยรุ่นไทยสุขภาพดี จำนวน 51 ราย (ชาย 25 ราย, หญิง 26 ราย) อายุ 16-19 ปี วัดไขมันร่างกายด้วยวิธีชั่งน้ำหนักใต้น้ำ และวิธี dual energy X-ray absorptiometry (DEXA) ซึ่งเป็นวิธี 2C และ 3C ตามลำดับ การชั่งน้ำหนักใต้น้ำในการหาความหนาแน่นร่างกายการวัด DEXA ในการหามวลแร่ธาตุกระดูกและมวลโปรตีน และใช้ไอโซโทปเสถียร deuterium oxide ในการหาปริมาณน้ำในร่างกาย จากนั้นใช้ สมการของ Lohman ในการคำนวณหาร้อยละไขมันร่างกายแบบ 4C ซึ่งเป็นการวัดที่มาตรฐาน*
ผลการศึกษา: *ค่าความหนาแน่นร่างกาย, ปริมาณน้ำ, ความหนาแน่นกระดูก และมวลปราศจากไขมันของผู้ชายสูงกว่าผู้หญิง ขณะที่ค่าไขมันร่างกายในผู้หญิงจะสูงกว่าผู้ชายอย่างมีนัยสำคัญทางสถิติ ($p<0.001$) เปรียบเทียบร้อยละไขมันด้วยวิธีการชั่งน้ำหนักใต้น้ำกับวิธีการแบบ 4C โดยใช้การวิเคราะห์การถดถอย พบว่าไม่เบี่ยงเบนจากเส้นเอกลักษณ์อย่างมีนัยสำคัญทางสถิติทั้งชายและหญิง (R^2 = 0.85 และ R^2 = 0.75 ตามลำดับ) ในขณะที่ร้อยละไขมันจากวิธี DEXA เบี่ยงเบนจากเส้นเอกลักษณ์อย่างมีนัยสำคัญทางสถิติเฉพาะผู้หญิง (R^2 = 0.59) แต่ไม่เบี่ยงเบนในผู้ชาย (R^2 = 0.60) วิธีการวิเคราะห์ Bland and Altman แสดงให้เห็นว่าร้อยละไขมันที่ใช้วิธีการชั่งน้ำหนักใต้น้ำและวิธี DEXA มีแนวโน้มต่ำกว่าความเป็นจริงในคนผอม และมีค่าเกินความเป็นจริงในคนอ้วน*
สรุป: *การวัดร้อยละไขมันโดยวิธีการชั่งน้ำหนักใต้น้ำ (2C) สามารถนำมาใช้แทนวิธีการวัดร้อยละไขมันแบบ 4C ได้ทั้งผู้ชายและผู้หญิง ขณะที่การวัดด้วยวิธี DEXA (3C) นำมาใช้แทนวิธี 4C ได้ในผู้ชาย ส่วนในผู้หญิงควรมีการศึกษาเพิ่มเติม การศึกษาครั้งนี้ได้พัฒนาสมการถดถอย สามารถนำมาปรับใช้กับวิธีการประเมินไขมันร่างกายแบบ 2C, 3C ที่ใช้กันทั่วไปเพื่อให้ได้ค่าใกล้เคียงกับค่า 4C ในวัยรุ่นไทย*