Research article

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Validation of new prediction equations using skin-fold thickness in estimating body fat percentage in children and adolescents

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Abstract

Objective: Prediction equations can be used as a useful, inexpensive, and highly accurate tool for estimating Percent Body Fat (PBF) in many countries all over the world. We conducted this study to develop new predictive equations for estimating PBF in children and adolescents aged 6 to 18 years in Ho Chi Minh City (HCMC), Vietnam.

Methods: This cross-sectional study included 149 students in HCMC. The new PBF prediction equations based on skinfold thickness and other anthropometric factors were evaluated using a multivariate linear regression model. The agreement between PBF estimated by equations and values derived from DXA measurements was assessed using the Bland-Altman method and Lin's concordance correlation coefficient (CCC). The performance of the new equations for the classification of nutritional status was studied using the ROC Curve and indicators such as AUROC, accuracy, sensitivity, specificity, and Youden-Index.

Results: Weight, height, and the sum of three skinfold thicknesses were added into the new equation for males (CCC = 0.87; R^2_{adj} = 0.76; RMSE = 4.06). Age, puberty status, the sum of three skinfold thickness measurements, and the sum square of subscapular and calf skinfold thicknesses were incorporated in the equations for females (CCC = 0.78; R^2_{adj} = 0.62; RMSE = 3.84). In comparison to BMI and WHtR, our equations proved to be more accurate in identifying individuals with an excess of body fat.

Conclusions: New prediction equations based on studied participants' skinfold thickness and anthropometric factors could produce predicted PBF estimates that are more consistent and accurate than other computed techniques utilizing DXA-derived PBF.

Keywords: Body composition; Dual-energy X-ray Absorptiometry; Obesity; Validation.

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1. INTRODUCTION

Obesity in children and adolescents is a major public health issue in the twenty-first century. This is a global matter that affects a large number of developing countries, particularly in urban areas [1]. In 2016, according to the statistics of the World Health Organization (WHO), the percentage of people aged 5 to 19 who were overweight or obese had increased dramatically (37% were overweight and 14% were obese) [2]. In 2016, 9.7% of Vietnamese children and adolescents were overweight, and 2.6% were obese [3]. If no effective interventions are implemented, this rate is anticipated to rise continuously.

Adipose tissue is considered to be the energy reserve for human body activities. Excessive body fat accumulation, on the other hand, causes a variety of conditions including metabolic syndrome, cardiovascular disease, fatty liver disease, and, in particular, overweight or obesity [4, 5]. Therefore, the determination of percent body fat (PBF) is crucial for identifying those who require early intervention, particularly in children and adolescents. Detecting subjects with high PBF utilizing the low-cost but high-sensitivity techniques can enable appropriate treatment therapy and lessen the emergence of comorbidities associated with the accumulation of excess body fat [6].

Dual-energy X-ray absorptiometry (DXA) is considered to be one of the "gold standard" direct methods for assessing body composition including PBF [7]. However, because of its limitations including high cost, cumbersome machinery, and requiring expert technicians, DXA cannot be extensively utilized as a community screening tool [8]. In addition, an anthropometric indicator equation can be used as an indirect method required to convert body density to the fat percentage for measuring PBF. This method gives non-invasive, accurate assessments of body fat in children and adolescents that may be used in the community and outside fixed facilities [9]. Many studies have developed and used this method [10]. Age, gender, weight, height, and skinfold thickness positions were included as common indicators in the predictive equations. Collecting these indicators needs only the use of simple, low-cost, non-invasive tools. However, the validity and applicability of equations to each target group remained limited due to differences in body composition characteristics between countries and ethnic groups.

Overweight and obesity are often categorized using the Body Mass Index (BMI), a simple index of weight-for-height. However, BMI does not differentiate fat from lean tissue, some predictions will be incorrect. In addition, factors such as gender, age, race/ethnicity during puberty, and physical activity could have impacts on body composition in ways that BMI cannot [11, 12]. In recent years, Waist Circumference (WC) and Waist-to-Height Ratio (WHtR) indicators have also been shown high correlation and agreement with PBF [13]. Many studies have found them to be more accurate than BMI in predicting risk factors for cardiovascular disease [14]. Therefore, we conducted this study to develop and assess the validity of newly developed sex-specific predictive equations based on anthropometric indicators of children and adolescents in HCMC, Vietnam in comparison with PBF derived from the DXA method.

2. METHODS

This was a cross-sectional study conducted on 6-18 years old students in District 10, HCMC in 2018 and 2019. The study included 149 children and adolescents (72 males and 77 females) from one senior high school, two primary and two junior high schools. Only classes of which teachers agreed to cooperate were invited to participate in the sample, and those whose both parents and themselves accepted to participate were selected. The study was approved by the Ethics Committee of Pham Ngoc Thach University of Medicine (Decision No. 132/QD-TDHYKPNT on April 4th, 2019).

Anthropometric data included weight, height, WC, and skinfold thickness. All measurements were based on a standard reference manual [15]. Weight was measured by electronic scale Tanita to the nearest 0.1 kilograms and height was measured using a Microtoise wall-height ruler to the nearest 1 centimeter. WC was measured to the nearest 0.5 cm with a non-elastic tape applied at a point midway between the lower border of the rib cage and the superior border of the iliac crest at the end of normal expiration. When measuring WC, subjects stood upright and a tape measure was applied around the middle, just above their hipbones. Triceps (TSF), Subscapular (SSF), and Calf (CSF) skinfold thickness were taken by the same trained and certified investigators using Caliper Harpenden. All measurements were done twice for each location to the nearest 0.1 millimeters using a standard measurement method [15] to ensure uniform techniques were applied. Body Mass Index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m2); WHtR was the quotient between WC and height. The body composition of participants was scanned by a DXA system administered by trained technicians at the Diagnostic Imaging Department of People Hospital 115 to ensure the safety of participants and quality of measurement. PBF was obtained automatically by Hologic QDR Discovery software.

Two pediatricians assessed pubertal development in male and female students separately, using diagrams that illustrated Marshall and Tanner's criteria [16] of male genitalia (GI-GV) as well as female breast development (MI-MV). According to a published study [17], the results were classified as pre-pubescence (stage I), pubescence (stages II-III), and post-pubescence (stages IV-V) [18]. All of the females who had menstruated were classified as post-pubescent (stage IV or V). Menarche was confirmed by asking female students if it had occurred or not.

Statistical analysis

Variables were first tested for normal distribution. Because distributions of the most skinfold thickness measurements were skewed, these variables were log transformed to improve the normality of data. Values were presented by mean and standard deviation except for Pubertal Assessment which was described by frequency and percentage. The Independence t-test was used to compare male and female differences in age, weight, height, WC, BMI, WHtR, TSF, SSF, CSF, and PBF as measured by DXA. The Chi-square test was used to investigate the statistical differences between genders at each pubertal stage.

Independent variables included squared, sum squared, and log-transformed terms of skinfold thickness variables. The pubertal stage was also obtained in the model as dummy variable. The predictor variables were examined by the univariate linear regression model to test the effects of the independent variables on PBF derived by DXA. Potential predictors kept to be entered into the model were variables with p-values less than 0.05. A multivariate model was analyzed by the backward Stepwise method to estimate PBF separately for male and female participants. The best predictors of PBF were decided on the basis of the highest adjusted determination coefficient (R_adj^2) and the lowest root mean square error of the estimate (RMSE) for each variable combination [19]. Regression assumptions will be checked on the final models, and any that fail will be eliminated. The accuracy, sensitivity, specificity, positive and negative predictive values of the regression model estimating the probability of obesity were determined to confirm the validity of our newly developed equations. The area under the receiver operating characteristics (AUROC) was also determined and illustrated by the ROC curve, which is generated by plotting True Positive Rate on the y-axis against the False Positive Rate on the X-axis. The best prediction method would yield a point in the upper left corner with the highest value for the Youden-J formula = (sensitivity + specificity -1) [20].

Bland-Altman plots and 95% limits of agreement were used to assess the agreement between PBF values estimated by new equations and PBF derived by DXA. PBF value differences were plotted against their mean. Lin's concordance correlation coefficient (CCC), and 95% confidence intervals for mean difference were calculated to compare how well the equations reproduce PBF using the DXA standard method.

Regarding the classification of participants' nutritional status by PBF, the following cut-off was used: ≥25% in males and ≥35% in women [1, 21]. As for WHtR evaluation, the cut-off point of 0.5 was used for both genders [22]. Obesity was also defined by BMI-for-age cut-offs as recommended by WHO [23].

3. RESULTS

Table 1 shows the characteristics of 149 participants consisting of 72 males (48.3%) and 77 females (51.7%). Among the anthropometric variables, there were significant differences between males and females in weight, WC, BMI, and CSF. The average value of PBF was 32% and female students had significantly higher PBF than males. There were no statistical differences between PBF estimated by Slaughter equations using TSF and SSF. PBF resulting from the TSF-CSF of Slaughter equation also shows that males had significantly lower PBF than that female participants.

Table 1: Demographic, anthropometric and body composition characteristics of participants, stratified by gender

Variables	Total (n = 149)	Male (n = 72)	Female (n = 77)	p-valuea
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	
Descriptive characteristics				
Age (year)	11.9 (3.2)	12.0 (3.3)	11.8 (3.2)	0.623
Weight (kg)	45.8 (15.9)	49.1 (18.1)	42.7 (12.9)	0.015*
Height (cm)	145.8 (16.3)	147.9 (18.2)	143.9 (14.2)	0.141
WC (cm)	71.7 (11.4)	73.8 (11.9)	69.7 (10.6)	0.030*
WHtR	0.5 (0.1)	0.6 (0.1)	0.5 (0.1)	0.146
BMI (kg/m^2)	20.9 (4.0)	21.6 (4.0)	20.2 (4.0)	0.035*
Skinfold Thickness				
TSF (mm)	17.3 (7.1)	16.7 (6.5)	17.8 (7.7)	0.321
SSF (mm)	14.8 (8.1)	13.7 (5.3)	15.8 (9.9)	0.108
CSF (mm)	18.1 (9.7)	13.5 (5.5)	22.4 (10.8)	< 0.001*
Percent Body Fat				
PBFDXA (%)	32.0 (7.5)	30.0 (8.2)	33.9 (6.2)	0.001*
$PBF_{Slaughter\ TSF\text{-}CSF}$ (%)	26.5 (9.7)	23.2 (8.3)	29.7 (9.9)	< 0.001*
$PBF_{Slaughter\ TSF\text{-}CSF\ 1}$ (%)	26.0 (9.4)	24.6 (8.9)	27.3 (9.8)	0.090
$PBF_{Slaughter\ TSF\text{-}CSF\ 2}$ (%)	26.5 (9.2)	25.7 (8.4)	27.3 (9.8)	0.297
	n (%)	**n (%)**	**n (%)**	
Pubertal Assessment				
Pre-pubertal	49 (32.9)	32 (44.4)	17 (22.1)	0.004*
Pubertal	33 (22.2)	12 (16.7)	21 (27.3)	0.119
Post-pubertal	67 (45.0)	28 (38.9)	39 (50.7)	0.149

Abbreviations: WC - Waist Circumference; WHtR - Waist-to-Height Ratio; BMI - Body Mass Index; TSF - Triceps Skinfold Thickness; SSF - Subscapular Skinfold Thickness; CSF - Calf Skinfold Thickness; PBFDXA - PBF from DXA derived; PBFSlaughter 1 - PBF estimated by Slaughter equations for Black people; PBFSlaughter 2 - PBF estimated by Slaughter equations for White people.

*[a] p-value from t-test result * Statistical significance at $p < 0.05$.*

Table 2 presents the standard regression model estimating PBF for each gender using stepwise backward multiple linear regression analysis. The results for male students included the following variables: weight, height, and total skinfold thickness of 3 positions. This model explained 76% of PBF variance in males. However, for female students, significant predictors of PBF were age, pubertal status, total skinfold thickness of 3 positions, and the sum square of TSF and CSF, accounting for 62% of PBF variance in female students.

Table 2: Multivariate regression models for estimating percent body fat for each gender

	Equations	$\mathbf{R^2_{adj}}$	**RMSE**
Male (n=72)	PBF = 90.157 + 0.262*Weight – 0.553*Height + 0.198*(TSF+SSF+CSF)	0.76	4.06
Female (n=77)	PBF = 26.627 – 0.846*Age + 4.579*Pubetal + 3.149*Post-pubertal + 0.337*(TSF+SSF+CSF) – 0.003*(SSF+CSF)2	0.62	3.84

Abbreviations: TSF - Triceps Skinfold Thickness; SSF - Subscapular Skinfold Thickness; CSF - Calf Skinfold Thickness; R^2_{adj} *- Adjusted R2, coefficient of determination; RMSE: Root Mean Square Error.*

Pubertal stages are defined as dummy variables:

- *Pre-pubertal participants: Pre-pubertal=1; Pubertal=0; Post-pubertal=0.*
- *Pubertal participants: Pre-pubertal=0; Pubertal=1; Post-pubertal=0.*
- *Post-pubertal participants: Pre-pubertal=0; Pubertal=0; Post-pubertal=1.*

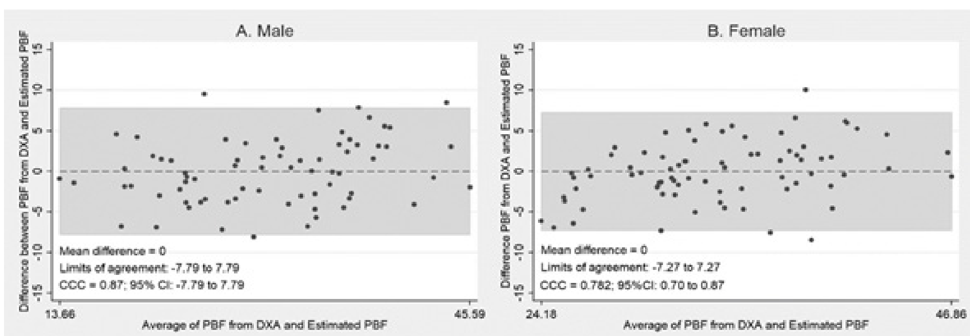

Figure 1: Agreement assessment between PBF estimated by new equations and PBF derived by DXA. Means are plotted against the difference between PBF from two methods. The center line represents the mean difference and the gray region represents limits of agreement

Bland-Altman plots in Figure 1 showed that the limit of agreement between PBF estimated by new equations and results from DXA was relatively narrow with a mean difference = 0. The predictive values were mostly dispersed within the limits of agreement (from -7.79 to 7.79 for males and -7.29 to 7.29 for females). Results of Lin's CCC also indicated that there was a strong concordance between estimated PBF values from the equation and DXA derived PBF (CCC=0.87 and 0.78 for males and females, respectively).

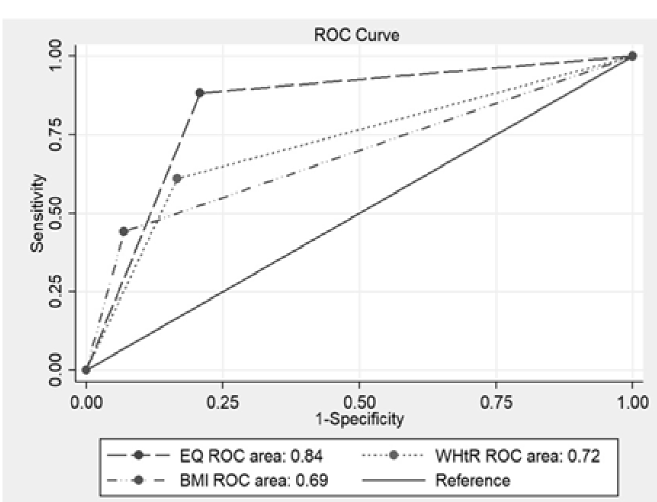

Figure 2: Area under Receiver Operating Characteristic demonstrating discriminatory power between different indicators in the prediction of obese children and adolescents. Abbreviations: EQ - Estimated equations; WHtR - Waist-to-Height Ratio; BMI - Body Mass Index

Table 3: Performance analysis of PBF predictors, stratified by gender

	AUROC	Accuracy	Sensitivity	Specificity	Youden- J
Male (n = 72)					
EQ	83.9	87.5	95.7	72.0	0.7
WHtR	73.8	69.4	59.6	88.0	0.5
BMI	71.4	63.9	46.8	96.0	0.4
Female (n = 77)					
EQ	79.8	80.5	76.7	83.0	0.6
WHtR	72.1	74.0	63.3	80.9	0.4
BMI	65.7	71.4	40.0	91.5	0.3

Abbreviations: EQ - Estimated Equations; WHtR - Waist-to-Height Ratio; BMI - Body Mass Index; AUROC: Area under Receiver Operating Characteristic.

Figure 2 and Table 3 show that BMI and WHtR had a low AUROC discriminatory power than that of our newly developed equations. When interpreting male and female students separately, our estimated equations continued to present better performance than the other two methods. It successfully predicted 83.8% of male and 79.8% of female children and adolescents with excess body fat. Although the positive predictive value of the regression model in males was relatively lower than that of BMI and WHtR, our model was consistently better in classifying non-obese participants.

4. DISCUSSION

Up till now, prediction equations have been validated and accepted as an indirect method of estimating PBF in many studies all over the world [10]. However, there hasn't been any prior research in Vietnam that addresses this yet. According to the findings of J Steinberger et al [24], PBF estimated by Slaughter equations was highly correlated with DXA scanning results (r=0.92, p=0.0001), hence we based on the Slaughter equations' suggestion of skinfold thickness variables to develop a new equation for Vietnamese children and adolescents.

There were similarities between our findings and those from other studies [25, 26]. Firstly, BMI was not a predictor of the model like in many other studies. Secondly, the sum and squared terms of skinfold thickness variables contributed more values to the regression model than single skinfold thickness. However, differentiate from the Slaughter equations [27], our study included age and maturation stage variables in PBF estimation model. The explanation could be because of the differences in the classification method of puberty between different studies. Nonetheless, age and menstrual status have been assumed to be directly related to PBF, so it is reasonable that these two variables contributed to the female PBF prediction model [28]. Compared to the two studies of Noël Cameron [25] and Taishi Midorikawa [26] which used more skinfold measurements than ours and included students who were all pre-pubertal, our prediction equation revealed lower R_adj^2 but higher RMSE, thus a weaker prediction could be expected as suggested by Chatterjee and Davide Chicco [19, 28]. In addition, because of no difference in the independent variables, R_adj^2 and RMSE between the equations for males and females from the two above studies were nearly equal, while in our study, the male model is better predictive than the female one as R_adj^2 was higher and RMSE was lower. We assumed that this disparity might come from the different measurements between the two technicians who separately collected skinfold thickness data for each gender.

The predictive values in the Bland-Altman plots of the new constructed estimation equations were scattered within the limits of agreement between the two methods. Cases that fell outside the limits of the two methods, on the other hand, were mostly above the upper limit, implying that our predictive equations provided a low estimate of PBF in cases with high PBF. Consequently, our prediction equations are likely to produce better results in participants with small and average skinfold thickness.

There are contradictory arguments about overweight and obesity screening tools. Currently, BMI is still a method of assessing nutritional status officially recommended by WHO [2]. However, it is criticized that BMI could underestimate the prevalence of obesity because it does not take into account the fat distribution which is directly associated with cardiovascular diseases and other health related risks [29]. Recently, scientific research also paid attention to WHtR and considered as a calculated indicator of obesity because of its success in identifying and predicting metabolic risk in children and adolescents [14, 30]. Not in line with these studies, our findings, nonetheless, indicated that predictive equations based on skinfold thickness and other anthropometric variables could provide a more accurate estimate of PBF in children and adolescents than BMI and WHtR. It could be suggested as a nutritional status assessment when DXA is not available due to its high positive predictive value, sensitivity, and specificity.

The strength of the present study is that the predictive equations newly developed were evaluated with R_adj^2 and RMSE which are considered as standard metrics to detect the quality of the performance of the regression analysis. The PBF estimated by the new equations agreed well with the DXA method results and outperformed the results of Slaughter's equations. However, the findings of the present study should be interpreted keeping in mind the following limitations: Firstly, this study was conducted on a rather small sample size for each age group. As the developed equations' predictions were retested among the same group, no estimate of prediction bias was given as a consequence. Secondly, to ensure the feasibility of the study, the sample was selected in a district of HCMC, hence may not be representative for whole Vietnamese children and adolescents. Therefore, the authors advise against using the predictive equations developed in this study to forecast body fat percentage in clinical settings, despite the fact that this study showed that it was a more effective way than other indices. More research should be planned to determine the accuracy and reliability of anthropometric characteristics and other skinfold thickness positions with larger and more diverse sample sizes. Despite those limitations, these equations were the first ones developed for children and adolescents in Vietnam that could be helpful for initiate application.

In conclusion, the new prediction equations based on a combination of skinfold thickness and anthropometric characteristics of the study participants may provide estimated results that are more in agreement and accurate with DXA than BMI and WHtR. Because of its low cost and ease of use, this can be considered an effective method for community scanning.

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