

# Development and Validation of a Skinfold Model for Estimation of Body Density for a Safe Weight Reduction in Young Iranian Wrestlers

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**Background:** Adverse effects of excessive body mass reduction among wrestlers dictate minimum weight determination through body composition. Although skinfold equations are essential to estimate body composition in the field setting, they are mostly derived from Western societies and may lack generalizability to other populations.

**Purpose:** Previously published skinfold equations lacked external validity in predicting body density of Iranian wrestlers. We aimed to derive a new anthropometric model specific to young Iranian male wrestlers.

**Study design:** Cross-sectional cohort study.

**Level of evidence:** Level 3.

**Methods:** One hundred twenty-six Iranian male wrestlers with at least 1 year of experience and a mean age of  $19 \pm 4.0$  years underwent underwater weight analysis for body density estimation and anthropometric measurements. The previously published equations were validated, followed by new regression modeling, using multivariable fractional polynomials, with body density as the criterion predicted by common anthropometric variables. The final model was validated throughout the modeling procedure using 1000 bootstrap replications.

**Results:** The mean body fat percentage (%BF) was 12.6% (95% CI, 11.9%-13.4%), lower than that of previous studies. Six previously published equations each had significant deviations from the line of identity (all  $P < 0.001$ ). The new prediction equation combined subscapular, tricipital, and midaxillary skinfolds and body mass index cubed to predict body density.

**Conclusion:** The development of ethnicity-specific equations, using statistically unbiased and comprehensive validation methods, is imperative for body composition estimation to determine the minimum weight for regulation of health in athletes.

**Clinical Relevance:** Using equations without external validation can bias the prediction of minimum weight, leading to unsafe weight reduction by athletes. Compared with a previous study, much lower mean %BF was found using an ethnicity-specific equation (12.6% vs 15.9%). This difference observed in %BF prediction could affect safe fat reduction in athletes.

**Keywords:** body composition; multivariable model building; external validation; wrestling; weight reduction

Excessive weight loss accounts for one of the major sources of concern among wrestlers<sup>27</sup> because of its adverse effects and, in some cases, mortality.<sup>5</sup> After the tragic death of 3

American collegiate wrestlers, a more stringent rule for minimum weight testing was set by the corresponding officials.<sup>18</sup> Despite these measures, rapid weight loss is still practiced widely and

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even more aggressively among adolescent wrestlers worldwide.<sup>7</sup> To take more effective action on an international scale, data from other parts of the world are sorely needed.

Iran is one of the leading countries in the sport of wrestling, and men widely engage in this popular sport. Recent studies have shown that deliberate mass reduction is common in Iranian wrestlers, but their mean body fat percentage is higher than that of their peers in the United States.<sup>12</sup> They concluded that Iranian wrestlers, with a mean percent body fat (%BF) of 15%, can safely use fat reduction methods to achieve a minimum weight of 5% to 7% body fat, as recommended by the National Collegiate Athletic Association (NCAA).<sup>11</sup> Since standard methods to estimate body composition are costly and time-consuming in field studies, predictive equations based on easier anthropometric measurements (eg, skinfold thickness) are often applied. However, the vast majority of published equations are developed in Western societies and can result in inaccurate predictions in populations with different anthropometric characteristics and nutritional habits.<sup>15,20</sup> Therefore, skinfold equations for prediction of body composition should be derived specific to the region under evaluation.

In absence of a gold standard for measurement of body composition, underwater weighing (UWW) is one of the methods extensively being implemented and approved by NCAA.<sup>1</sup> This measurement was pursued as the single criterion in the current study for a young Iranian wrestler sample to (1) validate existing predictive skinfold equations and (2) derive new anthropometric models to predict body density (BD) specific to our population, using unbiased statistical methods.

## METHODS

### Subjects

A total of 133 young wrestlers (mean age,  $19 \pm 4.0$  years; range, 13-30 years) with at least 1 year of experience, sampled from 28 clubs across Tehran, Iran, using a 2-stage cluster sampling method, were recruited for this study. The study protocol was approved by the Institutional Review Board of Tehran University of Medical Sciences, and written informed consent was obtained from all wrestlers prior to the study. Measurements were performed during the off-season. Participants underwent anthropometric measurements and densitometry using UWW in a single morning session under standard conditions. Athletes followed the study protocol of 8 hours of fasting, 12 hours of workout prohibition, and normal hydration prior to beginning the test session. Participants were also instructed to defecate and urinate before weighing. Seven participants did not show up on the measurement day.

### Procedures

Wrestlers' BDs were investigated by UWW in a  $170 \times 170 \times 150$ -cm custom tank with water at 33°C. A Sahand digital scale was employed to weigh participants on land to the nearest 0.05 kg in a seated position akin to that of UWW. Afterward, each participant sat on a metal chair suspended from a Sahand hanging scale with

0.05-kg sensitivity while his head remained above the water's surface. The underwater weight was recorded after the chair was tilted back to submerge the athlete's head. BD data were obtained from the average of the highest 3 values of 7 to 10 trials. Forced vital capacity (FVC) was measured to indirectly calculate residual volume (RV).<sup>3</sup> A portable Cosmed spirometer (KIT-Cosmed spirometer; Cosmed) was used to determine FVC (mean of 2-3 trials) after raising the participant's head above the surface. An additional 100 mL, correcting for intestinal gas, and obtained RV were subtracted from the body volume to calculate BD. Finally, the Brozek equation was used to obtain %BF.

Height was measured to the nearest 1.0 mm using a measuring tape while the athlete was standing on bare feet on a surface at 90° to the floor. Skinfold measurements were taken on the right side of the body using a Harpenden caliper to the nearest 0.1 mm at tricipital, subscapular, midaxillary, and chest sites using the landmarks described by Jackson and Pollock.<sup>10</sup> If the difference between the 2 measurements was more than 0.5 mm, a third measurement was taken and the mean of the 2 closest measurements was used. All skinfold measurements were conducted by an expert assessor experienced in measurement of skinfold thickness with calipers. The equipment used was calibrated to the manufacturer's standards.

### Statistical Analyses

Previously published skinfold equations were validated using the current cohort of wrestlers to evaluate their predictive performance. Equations that only included the skinfold sites measured were selected. The validity coefficient (Pearson correlation coefficient between actual and predicted body density [PBD];  $r$ ), constant error ( $\sum(PBD - BD)/N$ , where  $N$  is the total sample size; CE), standard error of estimate ( $S_y \sqrt{(1 - r^2)(n - 1)(n - 2)^{-1}}$ ; SEE), and pure error ( $\sqrt{\sum(PBD - BD)^2/N}$ ; PE) were calculated as measures of predictive accuracy. In addition, a calibration plot was created plotting the criterion values of BD against the predicted BD values. The intercept and slope of the calibration plot summarize how closely the predicted values match the observed values. A slope of 1 and an intercept of 0 indicate perfect fit.

The following variables served as potential predictors to construct this ethnic-specific model: (1) 4 separate skinfold thicknesses (ie, tricipital, subscapular, midaxillary, and chest) or the sum of their possible combination, (2) body mass index (BMI) or weight and height, and (3) age. To ascertain the best-fitting and the most realistic model, the multivariable fractional polynomial (MFP)<sup>22</sup> method was used to detect any monotonic but nonlinear relationships between predictors and the dependent variable (eg, BD obtained by UWW). The final equation was selected according to the Akaike information criteria,<sup>2</sup> root mean squared error (RMSE), and adjusted  $R^2$ . All analyses were conducted using Stata software (Stata Statistical Software: Release 11; StataCorp).

Finally, overcorrection bias, so-called "the optimism," was introduced into the full model using 1000 bootstrap replications. A large value of optimism addresses the greater need for further

Table 1. Descriptive characteristics and skinfold values for wrestlers (N = 126)

Variable	Mean (SD)	Range
Age, y	19.7 (4.0)	13-30
Weight, kg	73.9 (10.7)	48.5-108.1
Height, cm	173.6 (6.3)	156-187
BMI, kg/m <sup>2</sup>	24.47 (3.0)	18.5-37.8
BD, g/cm <sup>3</sup>	1.07 (0.01)	1.01-1.08
Body fat, % <sup>a</sup>	12.7 (4.5)	7.4-40.2
Skinfold, mm		
Triceps	11 (4.1)	1.9-30.5
Subscapular	12.8 (7.0)	6-72.5
Chest	7 (2.6)	4.1-17.4
Midaxillary	9.3 (4.6)	5.1-42

BD, bone density; BMI, body mass index.

<sup>a</sup>Brozek equation, percent body fat: %BF = [(4.57/BD) – 4.142] × 100.

external validation of the final model.<sup>23</sup> Model validation was performed using the Stata command “mfpboot” and the R “rms” package’s “validate” function. Type I error was set at the level of 0.05 throughout analysis.

## RESULTS

Baseline characteristics and anthropometric measurements are presented in Table 1. Results of the validation of the published skinfold equations (Table 2) on our sample are presented in Table 3. The paired-sample *t* test comparing the mean criterion BD and mean predicted BD (PBD) exhibited significant differences (CE; *P* < 0.001) for all equations except for the Tholand modification of the Lohman equation (*P* = 0.23). Also, the latter equation made a more accurate prediction in terms of PE (0.0062 g/cm<sup>3</sup>, approximately 2.53%BF).

Figure 1 plots the criterion BD against the PBDs obtained using the above equations in Table 2. All equations showed significant deviation from the line of identity (slope = 1, *P* < 0.001; intercept = 0, *P* < 0.001).

In the multivariable fractional polynomial analysis, chest skinfold did not survive the model selection procedure, and BMI cubed contributed significantly to prediction of BD, whereas age, height, and weight failed to improve predictive power of the final model. This final model explained 86% of the variance in BD (adjusted *R*<sup>2</sup>). The following is the final model formula:

$$\begin{aligned}
 \text{BD} = & -0.0115 \times \ln(\text{subscapular SF}) \\
 & - 0.00032 \times (\text{tricipital SF}) - 0.00032 \\
 & \times (\text{midaxillary SF}) - 0.0000005 \\
 & \times (\text{BMI})^3 + 1.11314
 \end{aligned}$$

where BD is body density and SF is skinfold. The full model underwent validation in 1000 bootstrap samples and revealed bias (ie, optimism) of near zero for all estimates of the regression analysis.

## DISCUSSION

Skinfold predictive equations specific to anthropometrics of Iranian young wrestlers were evaluated to estimate BD in an unbiased manner in field settings. UWW was applied as the criterion, strongly associated with a 4-component model.<sup>6</sup> In addition to the external validation of 6 previously published equations, internal validity of the newly established equation on our sample was evaluated as well. All but 1 of the published equations, established on foreign samples, made overtly inaccurate estimations of BD in our sample. We derived an equation that exhibited excellent predictive power with small error and slight deviation from the line of identity, which are signs of stability in future applications. In this study, the importance of a valid model-building procedure and assessment of bias in expected performance of the model on external data are stressed.

Body composition measurements using UWW in this sample showed different %BF (mean, 12.6%; 95% CI, 11.9%-13.4%) compared with previous studies conducted on Iranian high school (mean, 15.2%; 95% CI, 14.2%-16.1%)<sup>11</sup> or young male (mean, 15.9%; 95% CI, 15.2%-16.7%) wrestlers.<sup>12</sup> This discrepancy was seen despite the similarity in sample compositions and the population that they were drawn from in the latter case. One of the contributing factors might be that these studies did not employ standard methods and used published skinfold equations instead to estimate body fat. On the other hand, these results resembled more closely the mean

Table 2. Published skinfold prediction equations for body density applied for cross-validation

Study	Equation	$R^a$	SEE <sup>a</sup>
Lohman <sup>15</sup>	$BD = 1.101 - 0.0034(\text{sub} + \text{tri}) - 0.0022(\text{tri})^2$	—	—
Thorland et al <sup>25</sup>	$BD = 1.1136 - 0.00154(\text{sub} + \text{tri} + \text{mid}) + 0.00000516(\text{sub} + \text{tri} + \text{mid})^2$	0.81	0.0056
Boileau et al (1) <sup>4</sup>	$BD = 1.106 - 0.0034(\text{sub} + \text{tri}) + 0.000036(\text{sub} + \text{tri})^2$	—	0.0066
Boileau et al (2) <sup>4</sup>	$BD = 1.106 - 0.0036(\text{sub} + \text{tri}) + 0.000044(\text{sub} + \text{tri})^2$	—	0.0074
Boileau et al (3) <sup>4</sup>	$BD = 1.081 - 0.0008(\text{mid}) - 0.0022(\text{tri})$	0.79	0.0074
Parizkova <sup>19</sup>	$BD = 1.108 - 0.027\log(\text{tri}) - 0.0388\log(\text{sub})$	0.89	0.0100

BD, body density; mid, midaxillary;  $R$ , multiple correlation coefficient; SEE, standard error of estimate; sub, subscapular; tri, triceps.

<sup>a</sup>Values from the original studies.

Table 3. Cross-validation statistics for the published skinfold equations predicting body density (N = 126)

Equation	CE	$T$	$r$	SEE	PE
Lohman <sup>15</sup>	0.3531	12.8056 <sup>a</sup>	0.82	0.4725	0.4687
Thorland et al <sup>25</sup>	0.0007	1.1939	0.90	0.0063	0.0062
Boileau et al (1) <sup>4</sup>	0.0207	16.3768 <sup>a</sup>	0.21	0.0252	0.0250
Boileau et al (2) <sup>4</sup>	0.0200	11.4235 <sup>a</sup>	-0.13	0.0282	0.0280
Boileau et al (3) <sup>4</sup>	0.0207	35.9756 <sup>a</sup>	0.85	0.0218	0.0216
Parizkova <sup>19</sup>	0.0312	69.7766 <sup>a</sup>	0.89	0.0319	0.0316

CE, constant error; PE, pure error;  $r$ , Pearson product-moment correlation coefficient; SEE, standard error of estimate.

<sup>a</sup> $P < 0.001$  (paired-sample  $t$  test).

%BF reported for US high school and collegiate wrestlers, ranging from 6% to 12.8%.<sup>16,18,21</sup> Considering the small error associated with this new population-specific equation, reevaluation of previous data might be needed, which will also help cross-validate the equation. This would be deciding regarding the safe fat reduction method proposed by previous studies; considering the %BF obtained in this study, this method should be applied more cautiously.

In validation of the published equations, only the Thorland equation showed “very good” accuracy with regard to pure error (PE < 0.008 g/cm<sup>3</sup> or <3%BF)<sup>15</sup> and a nonsignificant constant error. This equation could predict %BF with 2.53% error; however, a lack of association between the observed and predicted values was indicated on the calibration plot (slope, 0.670; intercept, 0.353). Similarly, the Lohman equation selected by the NCAA<sup>14</sup> demonstrated poor predictions for our sample with significant CE (PE, 0.3531;  $R^2$ , 0.67; slope, 0.026; intercept, 1.051). Despite the widespread application of CE,  $r$ , SEE, and PE in cross-validation studies, it should be kept in mind that PE is

“the best single variable” reflecting the true difference between estimated and observed values, is preferred to  $r$ , and takes into account both the SEE and the CE.<sup>14,26</sup> Additionally, mean square prediction error (MSPE=PE<sup>2</sup>) is described as a better estimate than SEE for the predictive performance of the regression model in a different data set.<sup>17</sup> Hence, CE, SEE, and  $r$  were presented for the sake of comparison with previous studies; alternatively, for validation of the current model, the authors only opted for the pure error (PE, corrected RMSE) and MSPE (corrected MSE).

On the other hand, the bootstrap procedure was used to validate the derived models rather than the popular split-sample method applied in the vast majority of model validation studies.<sup>9,13,20</sup> The bootstrap is more efficient to validate predictive ability than other internal validation methods such as split-sample procedures or cross-validation.<sup>24</sup> The final model showed stable performance averaged over a 1000-bootstrap validation resampling, explaining 86% of variability in BD with an “ideal” PE (<0.0045 g/cm<sup>3</sup> or <2%BF)<sup>15</sup> of 0.0038 g/cm<sup>3</sup>, which corresponds to 1.62% of %BF. It also showed negligible

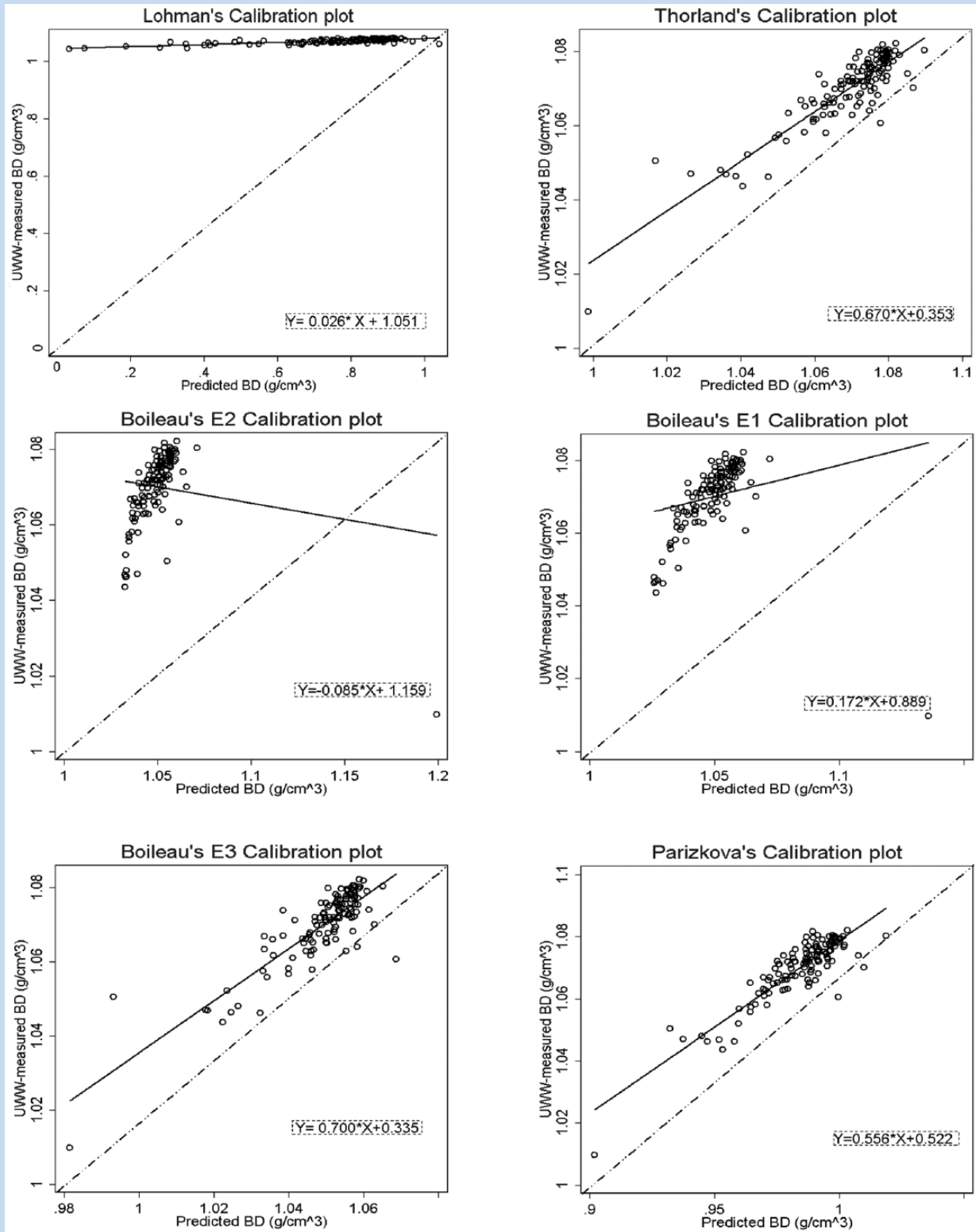


Figure 1. Calibration plots for published skinfold equations presented in Table 2. Solid lines are regression lines for observed criterion body density (BD) (Y), measured by underwater weighing (UWW), regressed on predicted body density (X) by skinfold equations. Slope and intercept of each corresponding regression line are presented. Dashed line indicates the line of identity (slope = 1, intercept = 0). All skinfold equations showed significant deviation from the line of identity (all  $P < 0.0001$ ). Note the different scaling for the Lohman plot; it was inevitably changed for better demonstration of the deviation from the equality line.

deviation from the line of identity. Furthermore, these estimates were corrected for overfitting bias (the optimism), the source of model failure in new data.

Limited skinfold measurement sites were a major limitation to this study. Because of the lack of instrumentation, the helium dilution method was not applied to calculate BD more properly. Also, using UWW will introduce some error due to inherent assumptions of 2-compartment methods (eg, consistency in hydration and density of fat-free compartments). Previous studies, however, concluded that 2-component and multicomponent methods performed equally in estimation of BD.<sup>6,8</sup> Finally, although the Brozek formula is frequently applied, it does not take into account the individual differences of the athletes compared with a multicomponent model.

Finally, deriving a relatively simple model based on wrestlers' anthropometrics, this study showed that effects of anthropometric variables on body composition differ across populations, and this should be taken into consideration when instituting rules for safer weight regulation among athletes in a specific region. Although widely overlooked, implementation of unbiased model building and validation strategies is vital to ensuring robust utility of the models for future predictions.

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