Progress in Nutrition 2020; Vol. 22, N. 3: e2020031 DOI: 10.23751/pn.v22i3.9315

Original article

Dual X-ray Absorbtiometry Can Predict Total and Regional Body Fat Percentage: A Comparative Study With Skinfold Thickness and Body Mass Index For Adult Women

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Summary. *Background and Purpose:* Distribution and volume of total and regional fat and fat percentage is important to monitor diet and exercise in adult women. A prediction formula for adult women by examining Body Mass Index (BMI), quotas obtained from Skinfold Thickness (ST) sites and body composition compartments determined by using Dual X-ray Absorptiometry (DXA) was aimed. *Participants and Method:* Sixty female participants (average age 46.4 ± 3.2 years; Range 40−55 years) were assessed by using DXA (Lunar Model DPX) to determine body fat percentage (%BF_{DXA}), Fat Mass (FM_{DXA}), and Lean Body Mass (LBM_{DXA}). Skinfold thickness sites were measured by using Skinfold Caliper (Holtain Caliper, UK). *Results:* A low positive correlation coefficients were found between %BF obtained from DXA and quota of suprailium ST (r=0.30 p<0.05). The highest correlation coefficient was between %BF_{DXA} and BMI: r = 0.83 (p<0.001). Three different Regression Equations were derived to predict %BF: BMI Model %BF = 7.162 + 0.23 * BMI (R^2=0.68 and SEE=2.892); Anthropometric 1, %BF = 7.346 + 0.835 * BMI + 0.169 * LE_{ST} (R^2 = 0.80 and SEE = 2.341); Anthropometric 2, %BF = 8.179 + 0.714 * BMI + 0.167 * LE_{ST} + 0.114 * Chest ST (R^2 = 0.80 and SEE = 2.341). Analysis of variance and confidence intervals and Bland & Altman Analysis were used to determine the validity. Intra Class Correlation (ICC) was used to determine reliability of the prediction equation. *Discussion*: The %BF_{DXA} findings of the present study was 38.29 ± 5.09 and %BF by Generalized Equation was 35.69 ± 4.79, are like in underestimating those in the previous scientific studies. Anthropometry Model 1, has predictors of BMI, is more advantegous having the least ST sites (mid-thigh and medial calf) than anthropometry Model 2. Otherwise BMI model is recommended. *Conclusion:* BMI, LE_{ST} (sum of the medial calf and mid-thigh) and chest ST values but not other ST quotas were good predictors for prediction equations. Derived models in predicting %BF using DXA of BMI model, Anthropometric 1, Anthropometric 2 were moreover valid and reliable. While the Generalized Equation was valid, it is not reliable for the adult women population.

Keywords: Dual X Ray Absorbtiometry, women, body composition, skinfold thickness, regression equation

Introduction

The physiological changes bring differentiation in the body composition compartments (1-5) and body topology (6) during advancing years of life for women. This differentiation in and the effects of the body composition compartments become more important for women due to health considerations such as cardiovascular diseases (7, 8), endocrine deficiency related health problems (9), risk of diabetes mellitus (10), bone health (1, 11-13) and menopause related factors with hormonal alterations (5, 12, 14-17) and deterioration of balance, flexibility, and muscle strength due to aging and inactive lifestyle (12, 18). Moreover, mortality and morbidity rates have been identified and reported by using Body Mass Index (BMI) as an indicator for diseases (8, 9). Recently, as endocrine system, the effects of fat mass (9, 19, 20) and muscle mass (21) on metabolism and vice versa have gained importance. The denominator of the percent of body composition compartments specifically of body fat and lean mass depend on each other by cell content and volume of each type of bone, muscle or adipose tissue (4, 22-25). Besides, the effect of the increase in fat mass and body weight as a body load and the decrease in muscle mass as a muscle pull effect and strength producer (4, 12) becomes more important in health considerations during advancing period of women life (1,17). Of the many regression formulas specific to adult population, Generalized Equation is the most commonly used one for adult women (26-28) however, adult women population spesific formula were derived mostly for young population (29, 30) and older women (30, 31). In addition, earlier studies on compression of skinfolds analyzed comparisons between the obtained values by skinfold calipers and the thickness of skin plus-fat measured on soft-tissue roentgenograms (32). However, during skinfold measurement compression, the resulting data for body composition compartments might result in an inaccurate estimation due to the differences in-adipose tissue content when examining advancing ages and adulthood. All the findings stated above suggested the following statement: Due to the lack of studies analyzing the validity and reliability of the Generalized Equations and the absence of a specific formula to be used for women during their transition period from young adulthood to older adulthood, the existence of useful, precise, and valid body composition assessment techniques was imperative for health care, nutritionists, sport, and exercise sciences.

Anthropometry, Dual X-Ray Absorbtiometry (DXA), hydrostatic weighing, bioelectrical impedance analysis, ultrasound, and magnetic resonance imaging were used to measure body composition compartments and to compare with each other for different populations (14, 15, 24, 33) As a criteria method, DXA gives detailed information about three body composition compartments of bone, fat, and lean body mass; therefore, it has been attractive recently due to easiness and convenience. On the other hand, BMI alone does not provide information on body composition compartments to qualify muscle mass, lean body mass and/or fat mass. Therefore, knowing the differences in the distribution and volume of regional fat and lean body tissues for the specific sites (14, 24, 25) would make scientific findings more interpretable. However, for the above-mentioned reasons, distribution of body fat percentage and/or total lean body mass of adult women population needed detailed investigation to evaluate the existing status for the women population at advancing ages by a timely nutrition intervention. Furthermore, regression models were intended to predict body composition compartments, but not to examine the regional skinfold thicknesses and BMI separately and/or together to provide detailed information. We hypothysed that there are correlations between % body fat obtained from DXA (%BF_{DXA}) and anthropometric variables of body weight (BW), height (H), BMI, skinfold thickness (ST). Additionally, Percent BF obtained from DXA, which is the criterion method can be predicted by using the anthropometric variables of for adult women.

2. Methods

2.1. Design

The study was designed to analyze and derive prediction equation models for body composition compartments by the dependent (%BF_{DXA}) and independent variables (BW, H, BMI, ST, quotas of ST, commonly used Σ of ST, sum of regional ST, quotas for each ST sites to the 7 ST, FM_{DXA} (kg), LBM_{DXA} (kg)).

2.2. Participants

Sixty female subjects (46.4 ± 3.2 years) participated voluntarily in the present study.

2.3. Materials

Data collection: All measurements were applied to standardize the assessments between 08.00—10.00am on the same day. The study complied with the Ethical Guidelines of Helsinki Declaration. Data collection lasted for three months.

2.4. Procedure

2.4.1. Anthropometric Measurements:

A wall-stadiometer (Holtain Ltd. U.K.) was used to measure height (H) of the subjects with barefoot to the nearest ± 0.1 cm with reference to the Frankfort plane horizontal. Body weight (BW) was measured by using ± 0.1 kg sensitive scale. Participants were barefoot and wore light shorts and t-shirts during weighing. Body mass index (BMI) was calculated as BW in kilogram divided by H in meters squared (kg/m^2). Skinfold Thickness sites of chest, midaxilla, suprailium, suprailiac, abdomen, subscapula, triceps, biceps, mid-thigh, and calf were measured by using Skinfold Caliper (Holtain Caliper, UK) as described in Eston and Reilly, (2013) (34). The quota for each ST site determined by multiplying the value of each ST site with 100 to equalize with Σ7ST assumed as total predictor. To determine the contribution of the distribution of ST sites, quotas for each of the ST site were named as Q-Biceps, Q-Triceps, Q-Subscapula, Q-Medial Calf, Q-Abdomen, Q-Mid-thigh, and Q-Suprailium. Sum of three (Σ3ST: thigh, suprailiac, triceps), sum of four (Σ4ST: triceps, suprailium, thigh, abdomen), and sum of seven ST (Σ7ST: biceps, triceps, subscapula, calf, abdomen, mid-thigh, and suprailium) were used to compare and analyze. ST distribution for lower and upper extremities were summed as proportional part of a total body. Regional ST was determined by sum of the pre-decided ST were as follows; Lower extremity (LE_{ST}): by sum of medial calf and mid-thigh; Upper extremity (UE_{ST}): by sum of biceps and triceps; Trunk1 ($T1_{ST}$): by sum of chest, abdomen, suprailium, midaxilla, and subscapula; Trunk2 ($T2_{ST}$): by sum of abdomen, suprailium, midaxilla, and subscapula. Body density (D_b) and %BF were calculated by using Generalized (26) and Siri (35) Equations.

2.4.2. Dual Energy X-Ray Absorptiometry (DXA)

DXA (Lunar, DPX Dual X-Ray Absorptiometry) allows to assess the total and regional body composition compartments using medium mode software with whole body scan. Trained technician performed the assessments with proper position and placement of markers. The DXA scanner was calibrated prior to whole body scan. Body Fat Percentage ($\%BF_{DXA}$), Fat Mass (FM_{DXA}) and Lean Body Mass (LBM_{DXA}) were obtained from whole body scan by DXA.

2.4.3. Statistical analysis of data:

All the descriptive statistics were presented as means ($\bar{x}$) ± standard deviations (SD) on the tables. Pearson Product Moment Correlation coefficients was run between body composition parameters between %BF and LBM obtained from DXA and ST'es to establish the relationships. Bland & Altman analysis was applied to determine the agreement between DXA parameters, BMI, Generalized Equations, and the Antropometric Models. A confidence level at 95% ($p \leq 0.05$) was considered as significant. Therefore, the 95% limits of the agreement were calculated as the mean difference ±1.96 SD of the differences between methods. Heteroscedasticity in between the methods of DXA and ST differences were systematically examined by plotting the absolute differences against the means and calculating correlation coefficients (36).

4. Results

The mean of BW values was found to be 66.13 ± 7.22 kg and the mean of the height values was 162.04 ± 7.22cm. ST sites with the highest contribution to Σ7ST quotas for mid-thigh was 21.02 ± 4.11mm (Range = 13.49 − 30.17mm) (Table 1). The results of the %BF of derived models were named according to the parameters used in the formula as **"BMI Model"**, "**Anthropometry 1", and "Anthropometry 2".** Of the several Generalised Equations used in the study by Jackson, Pollock and Ward (26), "Generalised Equation" derived by the sum of three skinfold sites thicknesses was referenced in the present study to predict %BF.

As shown in the Table 2, there were moderate-to-high significant positive relationships between $\%BF_{DXA}$ and ST sites ($r = 0.54 - 0,74$ $p<0.01$). The highest significant correlation coefficient value between $\%BF_{DXA}$ and anthropometric variable was the BMI ($r = 0.83$ $p > 0.01$). In addition, there were high significant

Table 1. Physical Characteristics of Adult Women (n=60)

Physical Parameters	x̄ ± SD	Range
Age (Years)	46.48 ± 3.17	40 – 55
Height (cm)	162.04 ± 7.22	143 – 176
BW (kg)	66.35 ± 8.77	46.0 – 85.0
BMI (kg/m²)	25.32 ± 3.42	19.02 – 35.09
%BF$_{DXA}$	38.29 ± 5.09	25.5 – 51.3
%BF-predicted by **BMI Model** **Anthropometry 1** **Anthropometry 2** **Generalized Equation**	 38.30 ± 4.21 38.30 ± 4.54 38.27 ± 4.60 35.69 ± 4.79	 30.56 – 50.32 26.86 – 48.86 26.52 – 47.98 21.99 – 45.14
FM$_{DXA}$ (kg)	25.04 ± 5.87	11.54 – 39.59
LBM$_{DXA}$ (kg)	39.67 ± 4.75	31.12 – 56.61
Biceps (mm)	13.51 ± 6.02	4.93 – 35.20
Triceps (mm)	27.38 ± 6.50	12.80 – 41.00
Subscapula (mm)	20.14 ± 8.70	8.73 – 43.47
Medial Calf (mm)	22.10 ± 7.33	6.53 – 38.27
Mid-Axilla (mm)	19.10 ± 7.49	4.87 – 38.60
Abdomen (mm)	35.15 ± 6.21	16.40 – 43.60
Chest (mm)	20.37 ± 7.61	4.80 – 33.60
Mid-thigh (mm)	35.95 ± 6.31	14.93 – 45.00
Suprailium (mm)	17.21 ± 7.48	5.40 – 41.00
Suprailiac (mm)	14.11 ± 6.40	3.93 – 32.20
Q-Biceps	7.54 ± 2.37	3.60 – 12.82
Q-Triceps	15.64 ± 1.94	12.49 – 21.21
Q-Subscapula	11.65 ± 2.47	7.51-16.28
Q-Medial Calf	12.71 ± 3.85	4.97 – 20.53
Q-Abdomen	20.36 ± 2.76	14.18 – 26.81
Q-Mid-thigh	21.02 ± 4.11	13.49 – 30.17
Q-Suprailium	9.44 ± 2.25	5.0 – 14.93
Σ3ST (mm)	86.95 ± 17.66	40.53 – 123.00
Σ4ST (mm)	115.70 ± 22.26	52.67 – 164.00
Σ7ST (mm)	176.31 ± 42.05	82.13 – 274.60
ΣUE$_{ST}$ (mm)	40.89 ± 11.55	19.73 – 76.20
ΣLE$_{ST}$ (mm)	58.05 ± 12.90	21.47 – 83.27
ΣT1$_{ST}$ (mm)	112.98 ± 32.91	50.47 – 192.60
ΣT2$_{ST}$ (mm)	92.61 ± 26.90	41.60 – 161.60

Table 2. Pearson Product Moment Correlation Coefficients between Σ7ST, %BF$_{DXA,}$ FM$_{DXA}$ (kg), LBM$_{DXA}$ (kg), ΣST sites (mm), ST sites (mm), and Quotas of Σ7ST.

	Σ7ST	**%BF$_{DXA}$**	**FM$_{DXA}$**	**LBM$_{DXA}$**
BW	0.57**	0.58**	0.87**	0.78**
BMI	0.77**	**0.83****	0.90**	0.33*
Arm Span	-0.11	-0.19	0.13	**0.72****
Biceps	0.70**	0.59**	0.66**	0.27*
Triceps	0.87**	**0.69****	0.72**	0.22
Subscapula	0.91**	0.62**	0.67**	0.23
Medial Calf	0.51**	**0,74****	0.66**	-0.03
Abdomen	0.80**	0.60**	0.59**	0.21
Chest	0.80**	0.54**	0.48**	-0.01
Mid-thigh	0.64**	**0.73****	0.63**	-0.03
Suprailium	0.88**	**0.67****	0.68**	0.16
Suprailiac	0.81**	**0.62****	0.69**	0.24
Q-Biceps	0.21	0.26*	0.35**	0.23
Q-Triceps	-0.25*	-0.15	-0.09	0.08
Q-Subscapula	0.59**	0.31*	0.42*	0.22
Q-Medial Calf	-0.20	0.25	0.16	-0.09
Q-Abdomen	-0.65**	-0.55**	-0.52**	-0.04
Q-Mid-thigh	-0.65**	-0.27	-0.35**	-0.19
Q-Suprailium	-0.60**	0.49**	0.50**	0.13
Σ3ST	0.93**	**0.80****	0.78**	0.17
Σ4ST	0.96**	**0.79****	0.78**	0.19
Σ7ST	XXX	**0.75****	0.76**	0.18
ΣUE$_{ST}$	0.85**	**0.70****	0.75**	0.26*
ΣLE$_{ST}$	0.60**	**0.77****	0.68**	-0.03
ΣT1$_{ST}$	0.98**	**0.69****	0.70**	0.18
ΣT2$_{ST}$	0.98**	**0.70****	0.72**	0.22

positive correlations between $\%BF_{DXA}$ and commonly used ΣST values of **Σ3ST**, **Σ4ST, and Σ7ST (0.80, 0.79, and 0.75 p<0.01, respectively). Additionally, the correlation coefficient values between regional ST sites (**ΣUE_{ST}, ΣLE_{ST}, $\Sigma T1_{ST}$, and $\Sigma T2_{ST}$) and $\%BF_{DXA}$ were 0.70, 0.77, 0.69, and 0.70, respectively (p<0.01). One of the highest significant relationship results between DXA and anthropometric parameters was between LBM_{DXA} and arm span, the correlation coefficient being 0.72 (p<0.01).

Excellent agreements were observed between %BF obtained by DXA and by each of the derived models: BMI Model, Anthropometric 1, and Anthropometric 2 (ICC = 0.90, 0.94, and 0.95 respectively p < 0.001). The highest ICC values were observed between derived Anthropometric 1 and Anthropometric 2 (ICC = 0.99 p < 0.001). ICC between BMI model and Anthropometric 1 (ICC = 0.96 p < 0.001) and between BMI model and Anthropometric 2 (ICC = 0.95 p < 0.001) were resulted in excellent reliability (P<0.001), while %BF by DXA, DXA-derived models of BMI Model, Anhropometric 1, and Anthropometric 2 and DXA-derived BMI, Anthropometric 1, Anthropometric 2 models and Generalized Equation resulted in poor reliability (ICC = 0.60, 0.64, 0.70, and 0.72 respectively; p < 0.01).

Discussion and Conclusion

The decrease in the amount of muscle mass quantity regarding LBM with loss in strength and the increase in fat mass with the results of morphological and physiological differenciation along advancing period. Therefore, by examining body composition compartments by BMI, ST, quotas of ST sites, and DXA and by deriving prediction equations for adult women could be count as

quotas advantageous belong to nutritionist, health care specialists, kineanthropometrist and scientists with the easiest way of overcoming the limitations of the skinfold assessment by BMI model. Moreover, body composition compartments with higher R2 antropometric models were derived, the reliability of the Generalised Equation (26) for adult women would be discussed in the present study.

Anthropometric Measurements

Notwithstanding the variation in fat distribution and content during advancing aging, achieving optimal body weight by reducing body fat mass is desirable. In the present study, the findings and the new approach to the assessment of the distribution of ST the findings assessments demonstrated strengthened the concernings in the differenciation of the body composition distribution and leading to a new perspective in health science and kineathropologists.

The values of skinfold sites and quotas of each site to the Σ7ST were shown in the Table 1. Highest skinfold thicknesses were measured in mid-thigh (35.95 ± 6.31mm; R = 14.93 – 45.00, second highest were abdomen (35.15 ± 6.21mm; R = 16.40 – 43.60), and third highest skinfold site was triceps (27.38 ± 6.50mm; R = 12.80 – 41.00). The ST results of the present study were subscapula 20.14 ± 8.70mm R = 8.73 – 43.47); medial calf (22.10mm ± 7.33; 6.53 – 38.27); mid-axilla (19.10 ± 7.49mm; R = 4.87 – 38.60); chest 20.37 mm ± 7.61; R = 4.80 – 33.60; mid-thigh 35.95 ± 6.31mm; R = 14.93 – 45.00). The findings suggest that subcutaneous fat distribution between the ages 40-55 years old women are different in anatomical pattern should be evaluated spesifically. Comparatively, such as $\%BF_{DXA}$ of 29.39 ± 5.52 years old young women (20 to 40years) had lower %BF than the results of the present study (26.25 ± 5.87; 14.60 to 39.60) (37). In addition to the results in the Battaro study (2002) (37) young women had the findings of lower Σ3ST (58.34 ± 11.82mm R = 36.50 to 88.00mm) and Σ7ST (119.85 ± 24.05 (mm) (73.00 to 167.50) (37) than in the present study results (Σ3ST = 86.95 ± 17.66mm R = 40.53 – 123.00mm and Σ7ST;176.31 ± 42.05mm; R = 82.13 – 274.60mm respectively).

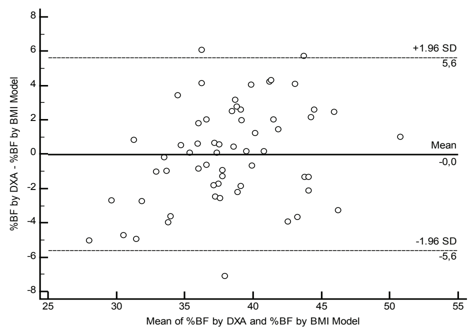
Recently, obesity studies were reported that fat mass (9, 19, 20) and muscle mass (21) effect endocrine system regarding endocrine and metabolism related health problems. The effect of distribution of the fat mass and obesity on releasing hormons or formation of the adiponectins were identified and discussed (19). For this reason, the differences in the distribution during advancing ages might not only related body composition but also related with health risk factors. In the present study, the data of the quota for each region to a Σ7ST were given in the table 1 and the correlation of each body compartment given in the table 2 for future studies to be comparable data. Highest quotas for each region to a Σ7ST were Q-Mid-thigh (21.02 ± 4.11; R = 13.49 − 30.17) and Q-Abdomen (20.36 ± 2.76; R = 14.18 − 26.81) the main loadings for the population. The values of the two quotas for each site to the Σ7ST make the trunk and leg fat important supported by Mueller and Stallones (1981) study (38).

The results demonstrated that the highest significant correlation coefficient result between $\%BF_{DXA}$ and anthropometric variable was the BMI ($r = 0.83$ $p < 0.01$), however there were only two significant moderate correlations between $\%BF_{DXA}$ and Q- sites of abdomen and suprailium (respectively). Returning to the aim of the present study, the body composition compartments showed significant positive correlation coefficients between the specific skinfold sites, its quotas', and regional sum of skinfolds sites. Such as, there were high significant positive correlations between $\%BF_{DXA}$ and Σ3ST, **Σ4ST, and Σ7ST (0.80, 0.79, and 0.75 p<0.01, respectively). Additionally, the correlation coefficient results between regional ST sites (**ΣUE_{ST}, ΣLE_{ST}, $\Sigma T1_{ST}$, and $\Sigma T2_{ST}$) and $\%BF_{DXA}$ of the adult were 0.70, 0.77, 0.69, and 0.70, respectively ($p<0.01$). The highest correlation between $\%BF_{DXA}$ and ST sites were medial calf and mid-thigh ($r = 0.74$ and $r = 0.73$, respectively $p<0.01$) makes leg fat important for advanging ages. The results also supported by the Mueller H and Stallones (1981) (38) that leg fat is important for the indexes used to describe the individual differences of adolescents and adult ages in the anatomical pattern of subcutaneous fat. Therefore, the importance for ΣLE_{ST} data as one of the most important predictors was supported by the earlier study (38). The insignificant correlation coeffients except for biceps ST ($r = 0.27$ $p<0.05$) between LBM_{DXA} (kg) and all the measured ST parameters are given in Table 2 were very low (between -0.19- +0.24 $p>0.05$). The findings demonstrated that by using subcutaneous fat mass couldn't be a predictor for LBM_{DXA} (kg) for this advanging aging women group. One of the recent studies with the similar age group (39) was not parallel with the present study that the correlation coefficients between appendicular muscle mass and anthropometric parameters of H, BW, BMI, triceps ST, mid-thigh ST, and medial calf ST were 0.55, 0.87, 0.67, 0.56, 0.38, and 0.43 respectively ($p<0.01$). The only high significant correlation parallel with the present result of the study was LBM_{DXA} (kg) and BW (0.78 $p<0.01$) was expected. Another high significant correlation was between LBM_{DXA} (kg) and arm span (0.72 $p<0.01$) might be interpreted as bone density relation with the body density and arm span with H (subtracting or rating) relationships still not clear in scientific studies (40). Moreover, a very early study demonstrated that correlation coefficient between age and body density were significantly high negative ($r= -0.671$ $p<0.01$) for the older women and %BF were increasing through the fifth decade changes as increase as fatness (41) due to inner, nonsubcutaneous fat. Therefore, anthropometric data, distribution of ST, and the data of the quota for each site to the Σ7ST in the present study were helpful in comparing and interpreting for advanging aging women.

Regression Models

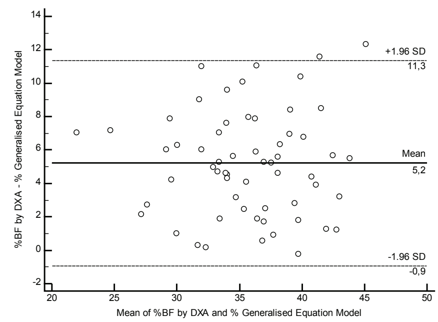
The main aim of the present study was that DXA as a reference method could predict both regional and whole-body compartment of fat mass and lean mass for women. Therefore, there were three different regression formulas derived in this study and validate Generalized Equation was compared with the $\%BF_{DXA}$. The need to cross-validate was examined for Generalized Equation and models to decide applicability to adult women population. To compare the prediction of the %BF of the four different regression model, The Bland & Altman plots for $\%BF_{DXA}$ and predicted values of the four equations of BMI Model, Generalized Equation Model, Anthropometric 1, and Anthropometric 2 were depicted in Fig. 1. ICC values were interpreted between to test the reliability of the predicted of BMI Model, Generalized Equation Model, Anthropometric 1, and Anthropometric 2 and DXA assessment.

(a) BMI Model



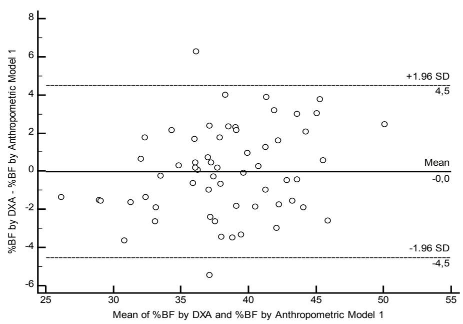
%BF = 7.162 + 0.23 * BMI
(R^2=0.68 and SEE = 2.892); r = - 0.32 p = 0.012

(b) Generalized Equation



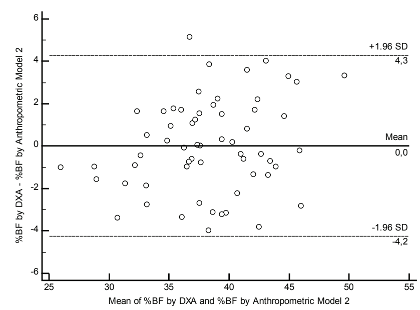
$D_b = 1.0994921 - 0.0009929(X_1) + 0.0000023(X_1)^2 - 0.0001392(X_2)$; %BF = [(4.95 /Db) −4.5] x 100 (Siri, 1961) r = − 0.035 p = 0.79

(c) Anthropometric Model 1



%BF = 7.346 + 0.835 * BMI + 0.169 * LE_{ST}
(R^2= 0.80 and SEE = 2.341); r = - 0.25 p = 0.06

(d) Anthropometric Model 2



%BF = 8.179 + 0.714 * BMI + 0.167 * LE_{ST} + 0.114 * Chest ST
(R^2 = 0.80 and SEE = 2.341) r = - 0.23 p = 0.08

Figure 1. Bland & Altman Scatterplots of mean %BF assessed by DXA; for 3 derived models by DXA – BMI Model; Anthropometric Model 1, Anthropometric Model 2; – and Generalized Equation.
Abbreviations: BMI=BW(kg)/H^2 $(m)^2$; LE_{ST}: Σ of medial calf and mid-thigh; Chest ST: skinfold thickness of chest; Generalized Equation(26). X_1 = Σ of triceps, suprailiac, and Mid-thigh ST, X_2 = Age (years)

BMI Model

One of the most important contribution of the study is the regression formula made using a single parameter of BMI with R^2 of 0.68 and SEE of 2.892. BMI is the easiest to measure and calculate but do not provide information about body composition compartments: BMI alone does not provide information on body composition compartments to qualify muscle mass, lean body mass and/or fat mass indicative for diseases. Recently, researchers were trying to seek more accurate and precise results to assess and compare body composition compartments using different regression formulas, technigues and methods (14, 15, 24, 25, 33, 37) For this reason, the study focused on the relationship between body compartments obtained from DXA and BMI, ST, and contribution of the regional ST. In this study, the three derived regression models also demontrated BIA and regional ST results were predictors for %BF for adult women, body composition compartments showed the agreement between Regression Models and DXA results. Despite the consistency in upper and lower limits for four model to predict %BF, there were very low negative significant relationship %BF values from DXA and Model BMI (r = - 0.32, p = 0.012) Within all findings, there was only one positive significant correlation between the differences in DXA and BIA Model magni-

Table 3. Intra Class Correlations (ICC) between predicted Models for %BF

Models	ICC*
BMI Model−Anthropometric 1	0.96
BMI Model−Anthropometric 2	0.95
BMI Model−Generalized Equation	0.64
Anthropometric 1−Anthropometric 2	0.99
Anthropometric 1- Generalized Equation	0.70
Anthropometric 2−Generalized Equation	0.72
ICC= 0.75 – 0.90 indicate good reliability; ICC > 0.90 indicate excellent reliability; ICC <0.75 indicate poor reliability; *all intraclass correlation coefficient, p < 0.001	

tude of %BF (i.e. heteroscedasticity) (Fig. 1). Bland & Altman scatterplot of $\%BF_{DXA}$ and %BF obtained from BIA Model allowed us to evaluate a very low negative significant (-0.32 p = 0.012) trend of differences.

Firstly, althougth R^2 was high, Bland & Altman Analysis, and trendline r value (r = -0.32 p = 0.012) was considerable in the present study. In addition to that finding, ICC value indicated excellent reliability between $\%BF_{DXA}$ and Model BMI was 0.90 (p < 0.001) (Table 3). BMI Model can comfortably be used to assess BF% for women 40 and 55 years old. The trendline r value demonstrated that while the mean of %BF of DXA and BMI model was increasing, predicted fat percentage was decreasing on the Bland & Altman Scatterplot. That means as the rate of fat increases, women were predicted less fatty. The bias seems to differenciate %BF prediction of BMI Model, becoming lower when the %BF is higher. Furthermore, the differences between the results seem to be constant, with a slight enlargement of the agreement limits, with a low correlation coefficient. Further on, we must consider that BMI parameter was an important predictor for %BF. The results of the present study also in line with the study of Korkusuz et al (42). The ages between 40-55 years period were the transition period for the advancing aging women population. Body composition compartments were changing morphologically with aging and during this menapousal transition period between ongoing to menopause and onset of menopause (6). Due to the shortening height of the vertebral bodies (43), H becomes shorter during advancing ages. In addition to decrease in H, BW increases or remains stable with advanging ages makes BMI higher (44). Exceptionally, average of body weight tends to decrease after the age of 60 (45). Consequently, it is highly recommendable to use BMI Model for adult women population between the ages of 40-55. In contrast to the present study, It was found that BMI was not a proper predictor for muscle mass as a lean body mass component for some of the adult women population (39).

Anthropometric Models (1 and 2)

In line with the assertions of the present study agreement, ICC between the $\%BF_{DXA}$ and Anthropometric 1 and Anthropometric 2 were very high; 0.94 and 0.95 (p<0.01). The results of the present study in line with the Duz et al. (2009) (33) study that R^2 was 0.82 and ICC between $\%BF_{DXA}$ and derived ST method was 0.90 (p<0.01) for young female population. Within all findings, there was only one positive significant correlation between the differences in DXA and Anthropometric 1 and Anthropometric 2 magnitude of %BF (i.e. heteroscedasticity) (Fig. 1c and d). Bland & Altman scatterplot of $\%BF_{DXA}$ and %BF obtained from Anthropometric 1 and Anthropometric 2 allowed us to evaluate insignificant (r = -0.25 p = 0.06 and r = -0.23 p=0.08 respectively) trend of differences. Both Anthropometric models are valid and reliable. Anthropometry 2 has high R^2 (0.80) and very high ICC (0.95; p<0.01) between $\%BF_{DXA}$, it is probably difficult to measure chest ST by skinfold caliper. Therefore, if there is a trained and experienced kinanthropometrist or technician that knows how to use a skinfold caliper, both Anthropomery Model formulas are recommended. Moreover, Anthropometry 1, has predictors of BMI, is more advantegous having the least ST sites (mid-thigh and medial calf) than Anthropometry 2. Otherwise BMI model is recommended.

It is necessary to add the following information and it should be considered that; skinfold compressibility changes with aging (32) also differentiate the measurement reliability for the adult female population. For this reason, the volume of the soft tissue measurement should be taken into consideration for the reliability and validity of the formulas. For this reason, BMI as a predictor is very important in determining body composition compartments. Furthermore, using total body water with anthropometric parameters might also be helpful for follow-up for the female adult population.

Generalized Equation (26)

Although significant high correlations between $\%BF_{DXA}$ and Generalized Equation, and Bland Altman analysis interpretation showed useful, ICC results demonstrated poor reliability. The findings of the reliability might be the population differences of 40 and 55 years %BF compared to DXA. The population differences in the present study might indicate poor the ICC result, In the present study, the sample (ages between 40-55 years) was not like that of Jackson and Pollock (1980) (26). Despite very high significant correlation (r = 0.95 p<0.001) between $\%BF_{DXA}$ and Generalized Equation (Table 4), ICC result showed poor reliability (ICC = 0.60). The Figure 1 (b) scatterplot distribution also gives idea about the population %BF that this aging group was mostly 25%BF and over. In addition to the ST results demonstrated that ST quotas were distributed mainly abdomen and mid-thigh. Brasilian young non-obese healthy women study (37) found similar results with the present study that while compared to the mean of the%BF obtained from the Generalized Equation (**Σ3ST**), was 23.43%, underestimated the results of the $BF\%_{DXA}$ (26.25%). Similarly, Duz et al also found that Jackson Pollock and Ward (26) %BF results were lower than obtained from $\%BF_{DXA.}$ The findings of the present study was parallel the $\%BF_{DXA}$ results obtained from DXA: %BF was 38.29 ± 5.09 and %BF by Generalized Equation was 35.69 ± 4.79. Consequently, the results of this study are like those in the previous scientific studies for young female group (26, 33, 37) and elderly (46).

Due to the decrease in LBM with advancing ages might be 40% between the ages of 30 and 70 (47) even if body weight is the same as the age gets older, total body water and body density changes. Therefore, BMI is expected to be a predictor for %BF, but not expected for LBM. Because BW and H which were the denominators in calculating BMI which couldn't be consistent. Moreover, BMI as a predictor need to be stardardized in the advancing ages to categorize as obese or non-obese. The present study findings also supported that significant very weak correlation between LBM_{DXA} (kg) and BMI was 0.33 (p<0.05), but very high significant positive correlation between LBM_{DXA} (kg) and BW was 0.78 (p<0.01). The other relationship between LBM_{DXA} (kg) and arm span was 0.72 (p<0.01) might be related to concerning body density and arm span relationship that yet it is included in the controversial results of scientific studies (48).

All Derived Methods

To obtain regression formulas with higher R^2 to more precise %BF prediction, DXA scan should be calibrated relating with the body water percentage by using determined whole body water with bioelectrical impedance analysis or dueterium method to be written to the software with the total amount of information calibration status using suitable scan mode should

Table 4 Prediction Equations for %BFDXA , the coefficient of determination, ICC between %BFDXA and predicted models and correlation coefficients.

Equation	Used parameter	Formula	R^2	SEE	ICC	r
BMI Model	BMI	*%BF = 7.162 + 0.23 * BMI*	*0.68*	*2.892*	0.90	0.83*
Anthropometric 1	BMI, LE_{ST}	%BF = 7.346 + 0.835 * BMI + 0.169 * LE_{ST}	0.80	2.341	0.94	0.89*
Anthropometric 2	BMI, LE_{ST}, Chest ST,	%BF = 8.179 + 0.714 * BMI + 0.167 * LE_{ST} + 0.114 * Chest ST	0.80	2.341	0.95	0.90*

be tested contemporaneous with hydrostatic weighing. Therefore, specific formulations for the slimmy or fatty women population should be developed to spesify population. Also, the reason for the result might be the rate of water used in the calibration of DXA measurements. Due to the body water assumed to be fixed in the software of DXA, R^2 value could be misleading.

Knowing precise measurement and evaluation of the body composition compartments were become the needs for health consideration to nutritionists or clinicians. All the criteria, have limitations, which were not proven by different methodologies with the gold standart method, or criteria to establish an even greater reliability in the found results.

Decrease in muscle mass and age-related bone loss might occur in the advancing ages. There is a need to analyse anthropometric techniques to measure and evaluate with concerning compressiblity of the skinfold thickness and muscle and bone loss assessing muscle loss with getting older.

Different regional variation might increase depots on abdominal, upper or lower extremities, or trunk regions even in low or very low energy diets (49). Additionally, it is important to note that LE_{ST} (sum of mid-thigh and medial calf) values used in the young women population to predict body fat from lower limb skinfolds (50). Moreover, higher BMI or obesity degree might differentiate the results of the R^2 by using only BMI as a determinant for can increase the amount of error in predicting %BF. Total body water and impedance results might overestimate or under estimate the body compartments for the female adult population. The prediction R^2 might be increased by using the total body water quantity in the the software of the DXA for each subject.

Limitations

The study was conducted in adult women and therefore does not predict values for young and aged women. It would also not be appropriate to use the formula for males too.

Conclusion and Recommendation

It is difficult to determine the distribution of fat mass for total body fat by using easy and inexpensive method. Besides subcutaneous abdominal and visceral fat mass can be assessed by computer tomography or magnetic resonance imaging, moreover DXA and bioimpedance analysis were expensive, not easily accessible for nutritionist, endocrinologist and kineanthropometrists. Knowing the quotas of each site to the Σ7ST might be helpful in health-related risk factors for the future studies.

For female adult women, firstly, BMI and ST sites were good predictors. Secondly, the relationship between anthropometric parameters of BMI and ST and $\%BF_{DXA}$ were used to derive prediction formula and compare with generalized equation formula. It is important to highlight that the derived models were depicted good to excellent reliability ICC values proves applicable, valid and reliable prediction models for BF%. However, when comparing the antropometric models with the BMI Models of R^2, anthropometric models were superior to the BMI Model in R^2. DXA-derived %BF prediction models are valid and reliable for assessing body composition in adult women population. However, the preferable anthropometric parameter, BMI, does not require special training and has the least measurement error in determining body composition compartments, is important for many scientists. The present study contributes to the researchers, clinicians and nutritionists giving information about %BF by using BMI parameters as a BF% predictors. In the light of all findings, it is recommended to use BMI model which has high R^2. Preferences to select the anthropometric formula depends on the availability of anthropometric equipment and trained technician or kineatropometrists.

The present study demonstrated that developed prediction formula as the %BF of women increases %BF estimation increases. This result also proved once again that the prediction formulas should be developed specific for the spesific population. Due to physiological and morphological changes in adult population for advancing years of life, according to BMI parameters and traditional surface anthropometry could be used as parameters to determine body composition compartment.

Recommendation

It is recommendable to predict body fat for the female population by tracking or follow-up the change in the skinfold sites and sum of skinfolds together. Furthermore, to predict body composition of women ages over 40 years by using DXA, in contrast to rated skinfold thicknesses, traditional direct traditional surface antropometry, ST values were suggested.

Acknowledgments

The authors of this paper state that there are no conflicts of interest. We would like to thank to subjects in involving the study and technicians working Middle East Technical University Medical Center.

Potential conflict of interest

None declared.

References

1. Atik, OS, Gunal I, and Korkusuz F. Burden of osteoporosis. Clinical Orthopaedics and Related Research. 2006;443:19-24.
2. Baumgartner RN. Body composition in elderly persons: a critical review of needs and methods. Progress in food & nutrition science. 1993;17(3):223-260.
3. Baumgartner RN, Stauber PM, McHugh D, Koehler KM, and Garry PJ. Cross-sectional age differences in body composition in persons 60+ years of age. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. 1995; 50(6), M307-M316.
4. Kyle UG, Genton L, Slosman DO, and Pichard C. Fat-free and fat mass percentiles in 5225 healthy subjects aged 15 to 98 years. Nutrition. 2001;17(7-8), 534-541.
5. Sternfeld B, Bhat AK, Wang H, Sharp T, Charles P, Quesenberry JR. Menopause, physical activity, and body composition/fat distribution in midlife women. Medicine & Science in Sports & Exercise. 2005;37(7),1195-1202.
6. Sowers M, Zheng H, Tomey K, et al. Changes in body composition in women over six years at midlife: ovarian and chronological aging. The Journal of Clinical Endocrinology & Metabolism. 2007;92(3), 895-901.
7. Chandra Babu G, and Shantharajah SP. Optimal body mass index cutoff point for cardiovascular disease and high blood pressure. Neural Comput & Applic. 2019; 31: 1585.
8. Xia JY, Lloyd-Jones DM, and Khan SS. Association of body mass index with mortality in cardiovascular disease: New insights into the obesity paradox from multiple perspectives. Trends in cardiovascular medicine. (2019;29(4), 220-225.
9. Pasquali R, Casanueva F, Haluzik M, et al. European Society of Endocrinology Clinical Practice Guideline: Endocrine work-up in obesity. European Journal of Endocrinology. 2020;182(1),G1-G32.
10. Han TS, Al-Gindan YY, Govan L, et al. Associations of BMI, waist circumference, body fat, and skeletal muscle with type 2 diabetes in adults. Acta Diabetol 56. 2019;947–954.
11. Balagopal P, Proctor D, Nair KS. Sarcopenia and hormonal changes. Endocrine 1997;7(1),57-60.
12. Collins BC, Laakkonen EK, Lowe DA. Aging of the musculoskeletal system: How the loss of estrogen impacts muscle strength. Bone. 2019;123,137-144.
13. Tomlinson DJ, Erskine RM, Morse CI, and Onambélé GL. Body fat percentage, body mass index, fat mass index and the ageing bone: their singular and combined roles linked to physical activity and diet. Nutrients. 2019;11(1),195.
14. Ofori EK, Conde Alonso S, Correas-Gomez L, et al. Thigh and abdominal adipose tissue depot associations with testosterone levels in postmenopausal females. Clinical endocrinology. 2019;90(3), 433-439.
15. Marra M, Sammarco R, De Lorenzo, A, Iellamo F, Siervo M, Pietrobelli A, Contaldo F. Assessment of Body Composition in Health and Disease Using Bioelectrical Impedance Analysis (BIA) and Dual Energy X-Ray Absorptiometry (DXA): A Critical Overview. Contrast Media & Molecular Imaging, 2019; https://doi.org/10.1155/2019/3548284.
16. Svendsen OL, Hassager C, and Christiansen C. Age-and menopause-associated variations in body composition and fat distribution in healthy women as measured by dual-energy X-ray absorptiometry. Metabolism. 1995;44(3),369-373.
17. Greendale GA, Sternfeld B, Huang M, et al. Changes in body composition and weight during the menopause transition. JCI insight. 2019;4(5).
18. Irez GB, Ozdemir RA, Evin R, Irez SG, and Korkusuz F. Integrating Pilates exercise into an exercise program for 65+ year-old women to reduce falls. Journal of sports science & medicine. 2011;10(1), 105-111.
19. Panis C, Herrera A, Aranome AMF, et al. Clinical insights from adiponectin analysis in breast cancer patients reveal its anti-inflammatory properties in non-obese women. Mol. Cell. Endocrinol. 2014;382, 190–196.
20. Wayne D, Ojha S, Budge H, and Symonds ME. Origins of Adipose Tissue and Adipose Regulating Hormones. In Maternal-Fetal and Neonatal Endocrinology. 2020; 663-672. Academic Press.

21. Legård GE, and Pedersen BK. Muscle as an endocrine organ. In Muscle and Exercise Physiology 2019; pp. 285-307. Academic Press.
22. Abe T, Bell ZW, Dankel SJ, Wong V, Spitz RW, and Loenneke JP. The Water-Fat Separation Method for Determining the Fat-free Component of Subcutaneous Adipose Tissue in Humans: A Brief Review. Journal of Clinical Densitometry. 2018; https://doi.org/10.1016/j.jocd.2018.12.007
23. Abe T, Dankel J, Loenneke JP. Body fat loss automatically reduces lean mass by changing the fat-free component of adipose tissue. Obesity. 2019;27(3):357-358.
24. Glüer CC. 30 years of DXA technology innovations. Bone. 2017;104,7-12.
25. Lind L, Kullberg J, Ahlström H, Michaëlsson K, Strand R. Proof of principle study of a detailed whole-body image analysis technique, "Imiomics", regarding adipose and lean tissue distribution. Scientific reports. 2019;9(1), 7388.
26. Jackson AS, Pollock ML, Ward ANN. Generalized equations for predicting body density of women. Medicine and science in sports and exercise. 1980;12(3), 175-181.
27. Furushima T, Miyachi M, Iemitsu M, et al. Development of prediction equations for estimating appendicular skeletal muscle mass in Japanese men and women. Journal of physiological anthropology. 2017;36(1), 34.
28. Tahara Y, Yukawa K, Tsunawake N. Body density assessment utilizing skinfold thickness and age in Japanese women. [Nihon koshu eisei zasshi] Japanese journal of public health. 1995;42(2), 84-94.
29. Côté KD and Adams WC. Effect of bone density on body composition estimates in young adult black and white women. Medicine and science in sports and exercise. 1993;25(2), 290.
30. Clasey JL, Kanaley JA, Wideman L, et al. Validity of methods of body composition assessment in young and older men and women. Journal of Applied Physiology. 1999;86(5), 1728-1738
31. Ling CH, de Craen, AJ, Slagboom PE, et al. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. Clinical Nutrition. 2011;30, 610-615.
32. Brožek J and Kinzey W. Age changes in skinfold compressibility. Journal of gerontology. 1960;15(1), 45-51.
33. Duz S, Kocak M, and Korkusuz F. Evaluation of body composition using three different methods compared to dual-energy X-ray absorptiometry. European Journal of Sport Science. 2009;9(3), 181-190.
34. Eston R, and Reilly T. Kinanthropometry and exercise physiology laboratory manual: tests, procedures and data: volume two: physiology. Routledge. 2013;29-35pp.
35. Siri, WE. Gross composition of the body. In. J.H. Laerence and C.A. Tobias (Eds.) Advance in Biological and Medical Physics IV. New York: Academic Press Inc. 1956;(4):239-280.
36. Bland JM, and Altman DG. Measuring agreement in method comparison studies. Statistical methods in medical research. 1999;8(2),135-160.
37. Bottaro MF, Heyward VH, Bezerra RF, and Wagner DR. Skinfold method vs dual-energy x-ray absorptiometry to assess body composition in normal and obese women. J Exerc Physiol Online. 2002;5(2), 11-8.
38. Mueller WH, and Stallones L. Anatomical distribution of subcutaneous fat: Skinfold site choice and construction of indices. Human Biology. 1981;321-335.
39. Rathnayake N, Alwis G, Lenora J, and Lekamwasam S. Development & cross-validation of anthropometric predictive models to estimate the appendicular skeletal muscle mass in middle-aged women in Sri Lanka. The Indian journal of medical research. 2019;150(3), 297.
40. Küçükkubaş N, and Korkusuz F. What happens to bone mineral density, strength and body composition of ex-elite female volleyball players: A cross sectional study. Science & Sports, 2019;34(4), e259-e269.
41. Young CM, Blondin J, Tensuan R, and Fryer JH. Body composition studies of "older" women, thirty to seventy years of age. Annals of the New York Academy of Sciences, 1963;110(2), 589-607.
42. Korkusuz F, Işıklı S, Akın S, Ungan M, Şenköylü A, and Aras NK. Precision of a dual energy X-ray absorptiometry device. Journal of radioanalytical and nuclear chemistry, 2004;259(3), 365-368.
43. Diacinti D, Acca M, D'erasmo E, Tomei E, and Mazzuoli GF. Aging changes in vertebral morphometry. Calcified tissue international. 1995;57(6), 426-429.
44. Hughes VA, Frontera WR, Roubenoff R, Evans WJ, Singh MAF. Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. The American journal of clinical nutrition. 2002; 76(2), 473-481.
45. Seidell JC and Visscher TL. Body weight and weight change and their health implications for the elderly. European journal of clinical nutrition. 2000;54(3), S33-S39.
46. Barbosa AR, Santarem JM, Jacob WF, Meirelles ES, Marucci JM. Comparison of body fat using anthropometry bioelectrical impedance and DEXA in elderly women. Archivos latinoamericanos de nutricion. 2001;51(1),49-56.
47. Cohn SH, Vartsky D, Yasumura S, Sawitsky A, Zanzi I, Vaswani A, and Ellis KJ. Compartmental body composition based on total-body nitrogen, potassium, and calcium. American Journal of Physiology-Endocrinology And Metabolism. 1980;239(6), E524-E530.
48. Lunt M, Felsenberg D, Adams J, et al. Population-based geographic variations in DXA bone density in Europe: the EVOS study. Osteoporosis international. 1997;7(3), 175-189.

49. Zamboni M, Armellini F, Turcato E, et al. Effect of weight loss on regional body fat distribution in premenopausal women. The American journal of clinical nutrition. 1993;58(1), 29-34.
50. Eston RG, Rowlands AV, Charlesworth S, Davies A, and Hoppitt T. Prediction of DXA-determined whole body fat from skinfolds: importance of including skinfolds from the thigh and calf in young, healthy men and women. European journal of clinical nutrition. 2005;59(5), 695.

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