Original Article

Anthropometric predictive equations for estimating body composition

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Abstract

Background: Precise and accurate measurements of body composition are useful in achieving a greater understanding of human energy metabolism in physiology and in different clinical conditions, such as, cardiovascular disease and overall mortality. Dual-energy x-ray absorptiometry (DXA) can be used to measure body composition, but the easiest method to assess body composition is the use of anthropometric indices. This study has been designed to evaluate the accuracy and precision of body composition prediction equations by various anthropometric measures instead of a whole body DXA scan.

Materials and Methods: We identified 143 adult patients underwent DXA evaluation of the whole body. The anthropometric indices were also measured. Datasets were split randomly into two parts. Multiple regression analysis with a backward stepwise elimination procedure was used as the derivation set and then the estimates were compared with the actual measurements from the whole-body scans for a validation set. The SPSS version 20 for Windows software was used in multiple regression and data analysis.

Results: Using multiple linear regression analyses, the best equation for predicting the whole-body fat mass ($R^2 = 0.808$) included the body mass index (BMI) and gender; the best equation for predicting whole-body lean mass ($R^2 = 0.780$) included BMI, WC, gender, and age; and the best equation for predicting trunk fat mass ($R^2 = 0.759$) included BMI, WC, and gender.

Conclusions: Combinations of anthropometric measurements predict whole-body lean mass and trunk fat mass better than any of these single anthropometric indices. Therefore, the findings of the present study may be used to verify the results in patients with various diseases or diets.

Key Words: Anthropometry, body composition, dual-energy x-ray absorptiometry

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INTRODUCTION

Overweight and obesity in Iran, like other countries, is epidemic.[1] Excess body fat and obesity are a metabolic disorder characterized by increased whole body fat and are associated with a greater risk of hypertension, diabetes, coronary heart disease, and cancer – all major health concerns in developed and developing countries.[2,3] Obesity is generally defined by using the

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body mass index (BMI), which does not distinguish between the lean and fat components of body weight.[4] In addition, some anthropometric measures and indices such as waist circumference (WC), waist-to-height ratio (WHtR), hip circumference (HC), and waist-to-hip ratio (WHR) are also suggested as better indicators of obesity, as compared to BMI.[5] These anthropometric measurements have been instrumental in monitoring the obesity epidemic, as well as linking the obesity status with an increased risk for cardiovascular disease, type 2 diabetes, and mortality.[6,7]

Computed tomography (CT) and magnetic resonance imaging (MRI) are considered the gold standards for assessing central fat distribution, but their cost and radiation dose (in case of CT) is high. In contrast, dual-energy x-ray absorptiometry (DXA) is a relatively simple technique for evaluating total and regional adiposity.[8] This expedient technique involves the subjects lying on a scan platform for about five minutes, as an x-ray source and detector move over the body in a rectilinear motion. Although the DXA cannot distinguish between intra-abdominal and subcutaneous fat, research in adults showed strong correlations between trunk fat mass measured with DXA and intra-abdominal fat measured with CT or MRI.[9] There is an increasing interest to specifically estimate the whole-body lean mass, as it may better reflect the body protein reserves and nutritional status in disease and aging. Whole-body lean mass loss is a process associated with aging as well as with several diseases.[10] Furthermore, DXA has been validated against MRI to predict the whole-body lean mass.[11]

Most of the previous studies have concentrated on the prediction of whole-body fat mass with anthropometric indices. In this study we focus on the prediction of whole-body fat mass, whole-body lean mass, and trunk fat mass with anthropometric indices. Additionally, relatively little data on the prediction of whole-body fat mass, whole-body lean mass, and trunk fat mass with anthropometric indices has been investigated in the Iranian population.

Therefore, the present investigation is undertaken to predict the relationship of the various anthropometric measures with the composition variables for the whole body (whole-body fat mass, whole-body lean mass, trunk fat mass).

MATERIALS AND METHODS

Study population

This is a cross-sectional study comprised of 143 men and women, who were referred to the Osteoporosis Diagnosis and Body Composition Center for DXA scans, from April to October 2013. A questionnaire was given to obtain the subject's information on age, gender, medical history, family history, physical activity, alcohol use, dietary habits, and smoking history, under the supervision of clinicians. Men and women who reported chronic medical conditions and smokers were excluded. Also children and athletes were excluded from this study. This study was approved by the Health Research Ethics Board in Isfahan University of Medical Science.

Dual-energy x-ray absorptiometry measurements

Dual-energy x-ray absorptiometry scans of the whole body composition, that is, whole-body fat mass, whole-body lean mass, and trunk fat mass were measured using a Norland Model XR-800 scanner and analyzed with Norland Illuminatus DXA 4.4.0. The instrument was calibrated daily with the manufacturer's calibration standard. DXA provides precise measurements of body composition in humans. With the participant lying in a supine position on a padded table, an X-ray beam passes in a posterior-to-anterior direction through the bone and soft tissue upward to a detector. DXA uses a constant potential x-ray source (100 KV) and a K-edge filter (46.8 KeV) to generate two main energy peaks (40 KeV and 70 KeV). The ratio of the x-ray beam attenuation at the lower energy relative to that at the higher energy is used to distinguish fat from the fat-free mass (minus the bone component). The DXA trunk fat mass was determined from a region extending from the shoulders to the top of the iliac crest with the arms excluded, while using the whole body bone and body composition analysis.[12]

Anthropometry

Body weight (kilograms) was measured with the participants wearing light indoor clothing on an electronic balance accurate to 0.1 kg. Height without shoes was measured to the nearest 0.5 cm with a measuring tape. BMI was calculated as the quotient of weight over height squared (kilograms per meter squared). The WC was measured with a flexible and inelastic tape at the end of a normal expiration, taking care not to compress the tissues. The waist circumference was measured at the smallest circumference between the thorax and the hips. The hip circumference was measured at the largest circumference of the trochanters with a flexible and inelastic tape. The waist-to-height (WHtR) ratio was calculated using the equation: WHtR = WC (cm)/height (cm). Waist-to-hip ratio (WHR) was calculated by the equation: WHR = WC (cm)/HC (cm).

Statistical analysis

The data sets were split randomly into two parts, the derivation set included a sample of 100 subjects, to develop prediction equations, and the validation set including a sample of 43 subjects, to validate these equations. Multiple linear regression analysis was conducted to estimate prediction equations using the derivation set. Each of the dependent variables, whole-body fat mass, whole-body lean mass, and trunk fat mass were regressed on the predictor variables, BMI, WC, HC, gender, and age. The backward stepwise elimination procedure was applied to find a reasonable subset of predictor variables. Prediction models were also developed for BMI, WC, and HC alone, with the gender variable. The adjusted R^2 (coefficient of determination) and SSE (error some of squares) criteria were applied to compare the regression models. Using prediction equations, estimates for whole-body fat mass, whole-body lean mass, and trunk fat mass were calculated for the validation set, and the observed and predicted values were compared. SPSS version 20 was used for data analysis.

RESULTS

Table 1 shows the descriptive characteristics of the derivation (n = 100) and validation (n = 43) sets. On the basis of the Independent student's *t*-test for continuous variables and Chi-square test for categorical variables, there were no significant differences between the variables in the two sets ($P > 0.05$). Table 2 denotes Pearson correlation coefficients between each of the dependent variables (whole-body fat mass, whole-body lean mass, and trunk fat mass) and continuous predictor variables in all subjects. As shown in Table 2, the highest correlation coefficient was between the whole-body fat mass and trunk fat mass, with BMI, but the linear relationship between BMI and whole-body lean mass was less than the height and weight. There were no evident differences of correlations between height and weight with the whole-body lean mass. Table 3 shows the results of multiple regression models by using the backward stepwise elimination procedure for the derivation set. The prediction equations for the whole-body fat mass, whole-body lean mass, and trunk fat mass are given below:

Whole-body fat mass (kg) = – 11.938 + 1.606 *BMI – 8.511*Gender R^2 =0.839

Whole-body lean mass (kg) = +14.966 + 0.588 *BMI + 18.694*Gender + 0.137*WC – 0.138*Age R^2 =0.777

Trunk fat mass (kg) = – 9.361 + 0.760*BMI - 3.739 *Gender + 0.049*WC R^2 =0.801

Stepwise procedures led to the selection of gender and BMI for the whole-body fat mass, four variables

Table 1: Characteristics of studied subjects

	Derivation set (*n*=100)		Validation set (*n*=43)		*P* value
	Mean	SD	Mean	SD	
HC (cm)	104	14.377	100	11.639	0.185
WC (cm)	90	14.805	90	12.668	0.885
Gender (female=0, male=1)	0.23	0.422	0.37	0.489	0.080
Age (year)	47	11.172	49	11.547	0.541
Height (cm)	160	9.062	160	9.315	0.849
Weight (kg)	71.94	12.211	69.65	12.569	0.310
BMI	28.10	4.705	27.02	4.441	0.204
Whole-fat mass (kg)	31.230	9.868	27.523	8.621	0.054
Whole-lean mass (kg)	41.639	9.316	42.831	9.761	0.490
Trunk fat mass (kg)	15.565	5.243	13.707	4.791	0.058
WHR	0.8766	0.0975	0.8998	0.0948	0.191
WHtR	0.5701	0.100	0.5652	0.0796	0.776

SD: Standard deviation, BMI: Body mass index, WHR: Waist-to-hip ratio, WHtR: Waist-to-height, HC: Hip circumference, WC: Waist circumference

Table 2: Pearson's correlation coefficients for all subjects

	Total fat mass/*P* value		Total lean mass/ *P* value		Trunk fat mass/*P* value	
Age	0.142	0.091	−0.02	0.808	0.214	0.01
Height	−0.326	<0.001	0.747	<0.001	−0.267	0.001
Weight	0.602	<0.001	0.737	<0.001	0.648	<0.001
BMI	0.850	<0.001	0.236	0.005	0.850	<0.001
WHR	−0.014	0.873	0.328	<0.001	0.088	0.296
WHtR	0.615	<0.001	0.032	0.701	0.644	<0.001
HC	0.638	<0.001	0.085	0.312	0.616	<0.001
WC	0.541	<0.001	0.306	<0.001	0.596	<0.001

BMI: Body mass index, WHR: Waist-to-hip ratio, WHtR: Waist-to-height, HC: Hip circumference, WC: Waist circumference

Table 3: Result of multiple regression analysis with backward stepwise elimination procedure for the derivation set

Covariates	Regression coefficient	SE	*P* value	Adjusted R^2	SEE
Whole-body fat mass (kg)					
Intercept	−11.938	2.524	<0.001	0.839	1516.509
Gender (female=0, male=1)	−8.511	0.964	<0.001		
BMI	1.606	0.087	<0.001		
Whole-body lean mass (kg)					
Intercept	14.966	3.307	<0.001	0.777	1841.452
Gender (female=0, male=1)	18.694	1.073	<0.001		
Age	−0.138	0.041	0.001		
WC	0.137	0.041	0.001		
BMI	0.588	0.131	<0.001		
Trunk fat mass (kg)					
Intercept	−9.361	1.635	<0.001	0.801	526.349
Gender (female=0, male=1)	−3.739	0.571	<0.001		
WC	0.049	0.022	0.028		
BMI	0.760	0.070	<0.001		

SE: Standard error, SEE: Standard error of the estimate, BMI: Body mass index, WC: Waist circumference (gender, age, WC, and BMI) for whole-body lean mass, and three variables (gender, WC, and BMI) for the trunk fat mass. Hence, several models using each of the anthropometric variables to predict body composition were defined. Table 4 compares prediction models using the adjusted R^2 and SSE criteria for the validation set. The best model for predicting the whole-body fat mass is a combination of gender and BMI, with adjusted $R^2 = 0.808$ and SEE = 585.28. The best model for predicting the whole-body lean mass is a combination of gender, BMI, WC, and age, with adjusted $R^2 = 0.780$ and SEE = 818.88, and the best model for predicting trunk fat mass variables is a combination of gender, BMI, and WC, with adjusted $R^2 = 0.759$ and SEE = 226.59. Figure 1 denotes a high agreement between the observed and predicted values for the validation set.

DISCUSSION

Dual-energy x-ray absorptiometry-derived body compositions can in turn be used to predict overall mortality and cardiovascular-related deaths.[13] Precise and accurate measurements of body composition are useful in achieving a greater understanding of human energy metabolism in physiology and in different clinical conditions, as also in evaluating interventions.[14] Direct measures of body composition are currently impractical for widespread use in screening, for general health and fitness standards. The easiest method to assess obesity and risk of cardiovascular heart disease is by using anthropometric indices. Waist and hip circumferences are used to define the pattern of obesity.[9] Mortality risk is increased among those with BMI > 25.0 kg/m², and is greatly elevated among those with BMI exceeding 30.0 kg/m².[15] In a recent research, BMI compared to other anthropometric variables was a better single indicator for predicting body composition.[16] In this study we have demonstrated that BMI is the best single anthropometric predictor of whole-body fat mass (adjusted $R^2 = 0.680$ and SEE = 999.42) and trunk fat mass (adjusted $R^2 = 0.715$ and SEE = 274.81), with regard to gender. Recent studies indicate that BMI may incorrectly classify risk in children and athletes (who are excluded in this study).[17] Hence, further research is needed to show the effect of BMI in predicting body composition for these particular groups. Also further research is needed to test the hypothesis that racial/ethnic differences exist in both men and women in the relationship of anthropometric measures of body composition. Even though HC, WC, WHtR, and WHR may be useful to evaluate fat distribution,[18] the prediction equation using these indices is poor in predicting whole-body fat mass and trunk fat mass. Similarly, when the anthropometric indices are used alone, R^2 is low. Therefore, the anthropometric indices are combined and a single prediction equation is developed for all subjects.

A decrease in the SEE and/or increase in the R^2 is obtained by using more than one index, so the combination of anthropometric measurements can predict body compositions better than any of these single variables. The accuracy of predicting the body composition by using a combination of anthropometric indices is higher than when using BMI alone. Although some investigators have used age as a variable in body composition equations,[13] the present results suggest that age is just a representative indicator for the whole-body lean mass.

In conclusion, this study has been designed to evaluate the accuracy and precision of body composition prediction equations. The results of this study show that the new anthropometric prediction equations, validated against DXA, can be used to predict whole body composition. Thus, we now allow the determination of body composition accurately by an

Table 4: Comparison of model performance in the validation set

Covariates	Adjusted R^2	SEE
Whole-body fat mass (kg)		
Model 1: BMI alone	0.680	999.42
Model 2: HC alone	0.219	2438.26
Model 3: WC, Gender	0.388	1865.09
Model 4: HC, Gender	0.378	1894.74
Model 5: BMI, Gender	0.808	585.28
Model 6: WHR, Gender	0.195	2452.94
Model 7: WHtR, Gender	0.335	2025.43
Whole-body lean mass (kg)		
Model 1: BMI alone	0.050	3800.79
Model 2: WC alone	0.129	3484.44
Model 2: BMI, Gender	0.764	921.74
Model 3: BMI, Gender, Age	0.783	828.13
Model 4: WC, Gender	0.638	1413.32
Model 5: WC, Gender, Age	0.653	1320.88
Model 6: BMI, WC, Gender, Age	0.780	818.88
Model 7: WHR, Gender	0.534	1819.31
Model 8: WHtR, Gender	0.579	1645.60
Trunk fat mass (kg)		
Model 1: BMI alone	0.715	274.81
Model 2: BMI, Gender	0.741	243.32
Model 3: WC alone	0.051	914.89
Model 4: WC, Gender	0.330	744.81
Model 5: HC alone	0.228	914.89
Model 6: HC, Gender	0.278	679.13
Model 7: BMI, WC, Gender	0.759	226.59
Model 8: WHR, Gender	0.095	851.74
Model 9: WHtR, Gender	0.259	697.78

SEE: Standard error of the estimate, BMI: Body mass index, HC: Hip circumference, WC: Waist circumference, WHR: Waist-to-hip ratio, WHtR: Waist-to-height

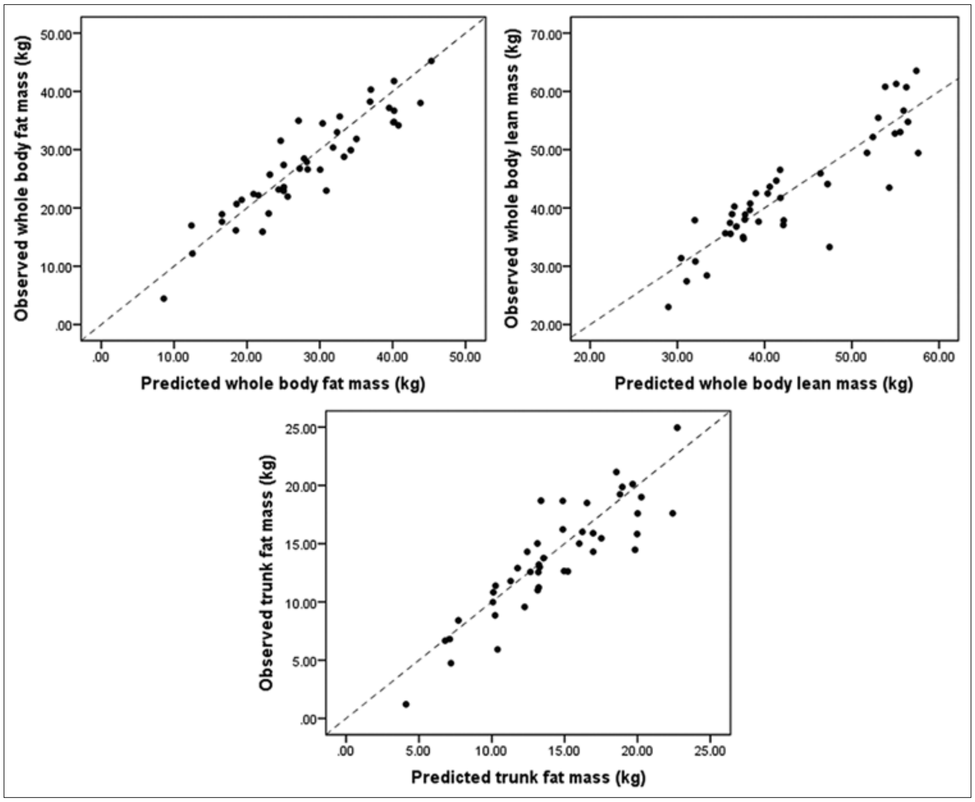

Figure 1: Plots of correlation between the predicted and observed values for the whole-body fat mass, whole-body lean mass, and trunk fat mass for the validation data set

easy, portable, and inexpensive method. Furthermore, the results of this study suggest that gender has an important effect on influencing the correlations of body composition and the studied anthropometric indices. Also a combination of anthropometric measurements can predict the whole-body lean mass and trunk fat mass better than any of these single anthropometric indices. Therefore, further studies using anthropometric indices to predict body composition values in samples from across the country is recommended.

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