Original Article

Use of Conventional Regional DXA Scans for Estimating Whole Body Composition

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Abstract

Background: Using soft-tissue composition in conventional regional dual-energy X-ray absorptiometry (DXA) scans of the spine and hip to predict whole body composition (whole-body fat mass, whole-body lean mass and trunk-fat mass) instead of a whole body DXA scan.

Methods: We identified 143 adult patients who underwent DXA evaluation of the whole body. Anthropometric indices were also measured. Datasets were split randomly into two parts; the derivation set including a sample of 100 subjects, and the validation set including a sample of 43 subjects. Multiple regression analysis with the backward stepwise elimination procedure was used for the derivation set and the estimates were then compared with the actual measurements from the whole-body scans for the validation set. The R_a^2 (adjusted coefficient of multiple determination) and SSE (error sum of squares) criteria were applied to compare regression models.

Results: Using multiple linear regression analyses, the best equation for predicting whole-body fat mass (R_a^2= 0. 945) included gender, height, weight, waist circumference (WC), spine fat fraction and hip fat fraction; the best equation for predicting whole-body lean mass (R_a^2 = 0. 970) included gender, weight, WC, spine fat fraction and hip fat fraction; and the best equation for predicting trunk-fat mass (R_a^2 = 0. 944) included gender, weight, spine fat fraction and hip fat fraction.

Conclusion: The results of this study show that regional DXA scans of the spine and hip can be used to accurately predict body composition.

Keywords: Anthropometry, body composition, dual-energy x-ray absorptiometry (DXA), hip fat fraction, spine fat fraction

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Introduction

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 well as evaluating interventions.[1] DXA-derived body composition can in turn be used to predict metabolic syndrome, including diabetes, hypertension, and cardiovascular disease and overall mortality.[2]

Many researchers use anthropometric indices [waist circumference (WC), waist-to-height ratio (WHtR), hip circumference (HC) and waist-to-hip ratio (WHR)] as the easiest way to evaluate body composition. Despite the simplicity of this definition and abundance of studies, there is also evidence that may mistakenly categorize risk in some individuals.[3,4]

Dual-energy X-ray absorptiometry (DXA) is most widely used for osteoporosis screening, assessment of fracture risk, and monitoring treatment of the lumbar spine and hip.[5,6] It is also a well-validated technique for assessing whole-body and regional soft-tissue composition (fat mass and lean mass).[7,8] For body composition analysis, scans are acquired for the whole body and not for the lumbar spine and hip regions.

The bone mineral measurement of the lumbar spine and hip requires correction for the soft tissue overlying bone that is achieved by estimating the composition of the soft tissue adjacent to the lumbar spine and hip.[9]

We hypothesized that regional fat tissue composition in the lumbar spine and hip regions with anthropometric indices could be used to estimate and predict whole body composition (whole-body fat mass, whole-body lean mass, trunk-fat mass) instead of whole-body scanning.

Material and Methods

Study population

This is a cross-sectional study comprised of 143 men and women who were referred to the Isfahan Osteoporosis Diagnosis and Body Composition Center for DXA scan of the lumbar spine, hip, and whole body on the same visit from April to October 2013. A questionnaire was administered to obtain information on the subjects' age, gender, medical history, family history, dietary habits and smoking history under supervision of a clinician. Men and women who reported chronic medical conditions and smokers were excluded. Also, children and athletes were excluded from

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this study. This study was approved by the Health Research Ethics Board in Isfahan University of Medical Sciences and informed written consent was obtained from each subject.

DXA measurements

DXA scans of the whole body composition, i.e. 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 on a daily basis with the manufacturer's calibration standard. 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 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.[10]

Anthropometry

Body weight (kilograms) was measured with participants wearing light indoor clothing on an electronic balance accurate to 0.1 Kg. Height without shoes was measured to the nearest 0.1 cm with a wall-mounted stadiometer. Body mass index (BMI) was calculated as the weight over height squared (Kilograms per meter squared). The WC was measured with flexible and inelastic tape at the end of a normal expiration and 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 on trochanters with flexible and an inelastic tape. WHtR was calculated by the equation: WHtR = WC (cm) /height (cm). Waist-to-hip ratio (WHR) was calculated by the equation: WHR = WC (cm) /HC (cm).

Statistical analysis

Datasets were split randomly into two parts; the derivation set including 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, and whole-body lean mass and trunk-fat mass were regressed on predictor variables, BMI, WC, HC, weight, height, spine fat fraction, hip fat fraction, gender, and age. The backward stepwise elimination procedure was applied to find a reasonable subset of predictor variables. In this method, the probability value was specified as 0.05 to enter a variable in the regression model and 0.1 to remove it. Prediction models were also developed for BMI, WHR, WHtR, WC, and HC alone and with gender variable. The R_a^2 (adjusted coefficient of multiple determination) and SSE (error sum of squares) criteria were applied to compare 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. The observed and predicted values were compared using Intra class correlation coefficient (ICC) and Bland-Altman plot with the 95% limit of the agreement. SPSS version 20 was used for data analysis.

Results

In this study, 23% in the derivation set and 37.2% in the validation set were men. According to Chi-square test, there was no significant difference between the proportions of men in the two sets at a significance level of 0.05 (*P* value = 0.080). Table 1 shows descriptive characteristics of the derivation (n = 100) and validation (n = 43) sets. Based on Independent student's *t*-test for continuous variables, there were no significant differences between variables in the two sets (*P* value > 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 whole-body fat mass and trunk-fat mass with BMI, but the relationship between BMI and whole-body lean mass is less than height and weight. There were no evident differences of correlations between height and weight with whole-body lean mass. Table 3 shows results of multiple regression models with the backward stepwise elimination procedure for the derivation set. Stepwise procedures led to the selection of gender, height, weight, WC, spine fat fraction, and hip fat fraction of the whole-body fat, 5 variables (gender, weight, WC, spine fat fraction, and hip fat fraction) for whole-body lean mass and 4 variables (gender, weight, spine fat fraction, and hip fat fraction) for trunk-fat mass. 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) = – 0.592 – 9.584*Gender – 0.097*Height + 0.587*Weight – 0.054*WC + 3.747*Spine fat fraction + 20.172*Hip fat fraction $R_a^2 = 0.946$

Whole-body lean mass (Kg) = + 11.170 + 8.731*Gender + 0.488*Weight + 0.041*WC – 3.116*Spine fat fraction – 17.099*Hip fat fraction $R_a^2 = 0.950$

Trunk-fat mass (Kg) = – 8.575 – 4.613*Gender + 0.257*Weight + 5.694*Spine fat fraction + 6.117*Hip fat fraction $R_a^2 = 0.923$

Furthermore, several models using each of the anthropometric variables to predict body composition were fitted for the derivation set. The prediction equations were applied to the validation set. Table 4 compares prediction models using R_a^2 and SSE criteria for the validation set. A decrease in the SSE and/or increase in the R_a^2 shows the accuracy of the model in predicting whole body composition. The best model for predicting whole-body fat was a combination of gender, height, weight, WC, spine fat fraction, and hip fat fraction with $R_a^2 = 0.945$ and SSE = 150.78. The best model for predicting whole-body lean was a combination of gender, weight, WC, spine fat fraction, and hip fat fraction with $R_a^2 = 0.970$ and SSE = 108.18, and the best model for predicting trunk-fat mass variables was the combination of gender, weight, spine fat fraction, and hip fat fraction with $R_a^2 = 0.944$ and SSE = 50.05. These results were similar to the method of backward stepwise elimination.

The predicted values of whole-body fat, whole body lean and trunk fat mass were calculated using the above prediction equations for the validation set. ICC of the predicted and observed values for whole-body fat was 0.979, ICC = 0.988 for whole body

Table 1. Characteristics of studied subjects.

Characteristics	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
Age	47.740	11.172	49.00	11.547	0.541
Height (cm)	160	9.062	160	9.315	0.849
Weight (Kg)	71.9	12.211	69.6	12.569	0.310
BMI	28.105	4.705	27.028	4.441	0.204
Spine fat fraction	0.663	0.294	0.606	0.224	0.259
Hip fat fraction	0.484	0.149	0.468	0.133	0.530
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	0.876	0.097	0.899	0.094	0.191
WHtR	0.570	0.100	0.565	0.079	0.776

SD = standard deviation; BMI = body mass index; WC = waist circumference; HC = hip circumference; WHR = waist-to-hip ratio; WHtR = waist-to-height ratio.

Table 2. Pearson's Correlation Coefficients for all subjects.

Covariate	Whole -body fat mass	Whole- body lean mass	Trunk fat mass
Age	0.142	-0.020	0.214*
Height	-0.326**	0.747**	-0.267*
Weight	0.602**	0.737**	0.648**
Body mass index	0.848**	0.236*	0.850**
Spine fat fraction	0.751**	-0.149	0.802**
Hip fat fraction	0.704**	-0.554**	0.644**
WHR	-0.014	0.328**	0.088
WHtR	0.615**	0.032	0.644**
HC	0.638**	0.085	0.616**
WC	0.541**	0.306**	0.596**

*P-value<0.05; ** P-value<0.001. BMI = body mass index; WC = waist circumference; HC = hip circumference; WHR = waist-to-hip ratio; WHtR = waist-to-height ratio.

Table 3. The result of multiple regression analysis with the backward stepwise elimination procedure for derivation set.

Covariates	Regression coefficient	SE	*P*-value	R_a^2	SSE
Whole-body fat mass (Kg)					
Intercept	-0.592	6.799	0.931	0.946	483.052
Gender (female = 0, male = 1)	-9.584	0.849	<0.001		
Height	-0.097	0.043	0.026		
Weight	0.587	0.031	<0.001		
WC	-0.054	0.022	0.019		
Spine fat fraction	3.747	1.362	0.007		
Hip fat fraction	20.172	2.820	<0.001		
Whole-body lean mass (Kg)					
Intercept	11.170	1.678	<0.001	0.950	407.908
Gender (female = 0, male = 1)	8.731	0.729	<0.001		
Weight	0.488	0.025	<0.001		
WC	0.041	0.020	0.046		
Spine fat fraction	-3.116	1.168	0.009		
Hip fat fraction	-17.099	2.558	<0.001		
Trunk fat mass (Kg)					
Intercept	-8.575	1.077	<0.001	0.923	200.078
Gender (female = 0, male = 1)	-4.613	0.500	<0.001		
Weight	0.257	0.014	<0.001		
Spine fat fraction	5.694	0.801	<0.001		
Hip fat fraction	6.117	1.781	0.001		

SE = standard error; R_a^2 = adjusted coefficient of multiple determination; SSE = error sum of squares; WC = waist circumference.

Table 4. Comparison of performance of the regression models in the validation set for whole-body fat mass (Kg), whole-body lean mass (Kg), and trunk fat mass (Kg).

Covariates	Whole-body fat mass (Kg)		Whole-body lean mass (Kg)		Trunk fat mass (Kg)	
	R_a^2	SEE	R_a^2	SEE	R_a^2	SEE
Model 1: BMI alone	0.680	999.42	0.050	3800.79	0.715	274.81
Model 2: WC alone	-0.078	3364.94	0.129	3484.44	0.051	914.89
Model 3: WHtR alone	0.070	2904.39	-0.014	4059.29	0.131	837.81
Model 4: HC alone	0.219	2438.26	-0.006	4026.51	0.227	744.81
Model 5: WHR alone	-0.208	3772.12	0.158	3368.02	-0.193	1150.91
Model 6: WC, Gender	0.388	1865.09	0.638	1413.32	0.330	744.81
Model 7: HC, Gender	0.378	1894.74	-3.098	16009.89	0.278	679.13
Model 8: BMI, Gender	0.808	585.28	0.764	921.74	0.742	243.32
Model 9: WHR, Gender	0.195	2452.94	0.534	1819.31	0.095	851.74
Model 10: WHtR, Gender	0.335	2025.43	0.579	1645.60	0.259	697.78
Model 11: Gender, Weight	0.808	585.05	0.923	300.78	0.793	194.64
Model 12: Gender, Weight, Height	0.862	409.25	0.938	235.95	0.829	156.78
Model 13: Gender, Weight, Spine fat fraction, Hip fat fraction	0.944	161.09	0.967	122.34	0.944	50.05
Model 14: Gender, Weight, Spine fat fraction, Hip fat fraction, WHR	0.943	161.52	0.969	112.18	0.943	49.12
Model 15: Gender, Weight, Spine fat fraction, Hip fat fraction, WHtR	0.942	163.79	0.969	111.78	0.943	49.48
Model 16: Gender, Weight, Spine fat fraction, Hip fat fraction, WC	0.944	158.57	0.970	108.18	0.943	49.51
Model 17: Gender, Weight, Height, Spine fat fraction, Hip fat fraction	0.946	152.66	0.966	123.46	0.944	50.05
Model 18: Gender, Weight, Height, Spine fat fraction, Hip fat fraction, WHR	0.944	152.67	0.969	108.41	0.942	48.79
Model 19: Gender, Weight, Height, Spine fat fraction, Hip fat fraction, WC	0.945	150.78	0.567	1531	0.942	49.02

SE = standard error; R_a^2 =adjusted coefficient of multiple determination; SSE =error sum of squares; BMI = body mass index; WC = waist circumference; HC = hip circumference; WHR = waist-to-hip ratio; WHtR = waist-to-height ratio

lean and ICC = 0.974 for trunk fat mass. Figure 1 denotes Bland-Altman plots with 95% limits of the agreement. ICCs and plots show a high level agreement between observed and predicted values for whole body fat, whole body lean mass and trunk fat mass.

Discussion

Overweight and obesity is epidemic in Iran as in other countries.[11] Anthropometric measurements have been instrumental in monitoring the obesity epidemic, as well as linking obesity status with an increased risk of cardiovascular disease, type 2 diabetes, and mortality.[12,13] For example, there are recent indications that the cut points for high-risk waist circumference as endorsed by the World Health Organization (>102 cm for men and >88 cm for women); mortality risk is increased among those with BMI >25.0 kg/m^2, and is greatly elevated among those with BMI exceeding 30.0 kg/m^2. Also, BMI does not distinguish between lean and fat components of body weight.[14,15]

In recent research, HC, WC, WHtR, and WHR may have been useful to evaluate the fat distribution, but the prediction equation using these indices was poor in predicting whole-body fat mass and trunk-fat mass. However, compared to other anthropometric variables, BMI was the best single indicator for whole-body fat mass and trunk-fat mass with regards to gender. We derived fat masses from adjacent lumbar spine and hip scans and used these values as well as the anthropometric indices to predict body composition. Prediction equations using the combination of anthropometric indices and derived-fat masses predict whole-body fat (R_a^2 = 0. 945), whole-body lean (R_a^2 = 0. 970) and trunk-fat mass (R_a^2 = 0. 944) better than any of these anthropometric indices.

According to Table 4 and the values of R_a^2 and SSE, the effect of anthropometric indices (WC, WHtR, HC, and WHR) in predicting body composition of the models is negligible. Meanwhile, the main effect to increase the accuracy of prediction models is by use of spine fat fraction and hip fat fraction.

Research in ethnic groups suggests that the body composition changes with age[16] but in this research, age was not a predictor variable in the results from backward stepwise multiple linear regression and was not used in the final models. Furthermore, this study suggests that gender has an important effect on influencing the correlations of body composition and the studied variables. Therefore, further studies are recommended to predict body composition values in samples from various countries in age groups and within men and women categories. Studies indicate that BMI may incorrectly classify risk in children and athletes (who were excluded from this study).[3] Hence, further research is also needed to consider the impact of these particular groups on the survey results.

One limitation of this study was to perform scans of the spine, hip and whole body on the same visit. Although the number of patients who underwent DXA scan of all sites (spine, hip, and whole body) was adequate for the analysis, a cohort study in this field is recommended to confirm the accuracy of this study. This study can also be performed with other DXA scanner equipment for a more thorough result.

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 soft-tissue composition in regional DXA scans of the spine and hip can be used to predict whole body composition. Hence, the use of DXA scans of the

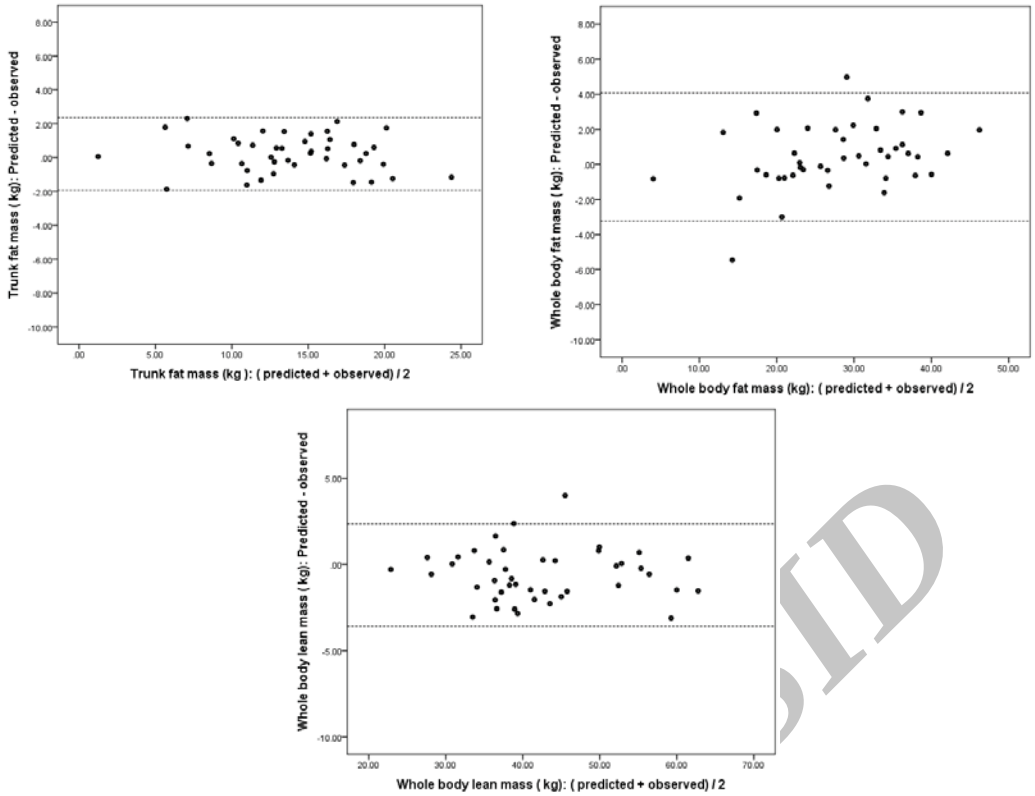

Figure 1. Bland-Altman Plots (difference between predicted and observed values versus the mean of the 2 values) for whole-body fat mass, whole-body lean mass and trunk-fat mass for the validation data set. Parallel outer lines are 95% limit of the agreement.

spine and hip saves a lot of time and expenses imposed on the patients and the health services, providing comprehensive information on bone mineral density of the most prone sites to osteoporotic fractures and body composition to investigate the relative risk of heart failures.

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