Menopause: The Journal of The North American Menopause Society
Vol. 19, No. 4, pp. 467-470
DOI: 10.1097/gme.0b013e31823110db

BRIEF REPORT

Development and validation of a simple model based on anthropometry: estimating fat mass for white postmenopausal women

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Abstract

Objective: The aim of this study was to develop and validate a simple anthropometric model that estimates the fat mass of white postmenopausal women and compare it to other models available in the literature.

Methods: Anthropometric data such as height, weight, waist and gluteal circumferences, biceps, triceps, suprailiac, and subscapular skinfolds, which were incorporated for the development and validation of this model, were derived from 276 white postmenopausal women. Dual-energy x-ray absorptiometry was used as the reference method. Furthermore, a comparison with other models was made using Bland-Altman analysis and intraclass correlation coefficient.

Results: The model developed in the current study was: fat mass = 0.069 × biceps + 0.553 × weight − 14.655 × height + 0.218 × gluteal circumference − 9.830 ($r^2 = 0.934$, $P < 0.001$). The Bland-Altman reliability analysis on the validation cohort showed a non-statistically significant bias of 0.158 kg and limits of agreement of ±4.21 kg; the intraclass correlation coefficient was 0.983. Furthermore, the validity of the current model also remained significant in different levels of BMI, ranging from 20.5-42 kg/m^2. When other models available in the literature were tested in the current cohort, bias ranged from −1.239 to −6.996 kg, while the limits of agreement from ±5.25 to ±8.05 kg.

Conclusions: The model developed in the current work was found to be valid for the assessment of postmenopausal women's fat mass at normal, overweight and obese BMI ranges, and can be easily applied in clinical practice and research.

Key Words: Fat mass – Dual-energy x-ray absorptiometry – Skinfolds – Hip circumference – Waist circumference.

Many chronic diseases such as cardiovascular disease (CVD), metabolic syndrome, diabetes mellitus, and cancer have been strongly linked to excess body fat.[1] Furthermore, women seem not to be threatened by CVD until menopause, but the risk increases after menopause because of several hormonal changes, which result in body composition changes as well. The latter include loss of fat free mass (FFM) and increased central adiposity,[2] among others.

Therefore, the accurate assessment of fat mass (FM) in postmenopausal women, both in clinical practice and in research, is of critical importance for estimating the risk concerning the previously mentioned obesity-related diseases. All "gold standard methods," such as underwater weighing, dual-energy x-ray absorptiometry (DXA), deuterium oxide dilution, and Bod Pod, cannot always be applied, even in research. This is mostly due to the fact that they are labor-intensive, costly, time-consuming, and laboratory based and can cause discomfort among volunteers because of physical exposure. One of the most widely used methods for estimating body composition is anthropometry (skinfolds; waist, gluteal, and upper arm circumferences; etc). Therefore, a large number of anthropometry-based models are available in the literature. However, the majority are quite complicated, invasive, and time-consuming and require patients' physical exposure.

Received February 5, 2011; revised and accepted July 28, 2011.

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All authors who have made an important contribution to this study are included and are thoroughly familiar with the primary data. The authors declare that their responsibilities were as follows: Y.M., G.M., and S.K. designed the study; S.K., O.A., K.M., A.G., and E.A. collected the data; and Y.M. and S.K. conducted the literature review, performed the statistical analyses, and wrote the manuscript.

Funding/support: This research has been co-financed by the European Union (European Social Fund-ESF) and Greek national funds through the Operational Program ''Education and Lifelong Learning'' of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

Financial disclosure/conflicts of interest: None reported.

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Furthermore, most of the models have resulted from populations with a wide age range or have accrued from samples of both sexes for sample-size reasons. The need for simple models based on target population groups with specific characteristics is generally acknowledged.

Therefore, the aim of the current study was to build and validate a model estimating the FM of white postmenopausal women based on simple and easily applied anthropometric measurements, using DXA as the reference method, and assess its accuracy compared with that of other models available in the literature that are potentially applicable to the same age and sex group.

METHODS

The sample size was 276 white postmenopausal women aged from 47 to 79 years (mean [SD] age, 62 [6.2] y) with a body mass index (BMI) range of 20.5 to 42 kg/m^2 and a mean (SD) waist-to-hip ratio of 84 (7.5) cm (mean [SD], 80 [6.2], 84 [7.7], and 86 [7] cm for those with BMI <25, 25-30, and >30 kg/m^2, respectively). Volunteers from the wider area of the city center of Athens were asked to attend our laboratory. Menopause was defined as the absence of menstruation for the last 2 years (mean [SD], 12.4 [6.9] y) and was assessed by means of questionnaires. None of the participants had any disease that might affect hydration status or body composition or needed clinical care. The population was randomly divided into two subsamples that did not differ significantly with reference to BMI, FM, age, weight, height, and physical activity. The first cohort consisted of 185 women (development cohort), whereas the second cohort had 91 participants (validation cohort), so that the equation could be, respectively, formed and validated. The study was approved by the ethics committee of Harokopio University and was conducted in accordance with the code of ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

Body weight and standing height were measured using a digital scale (Seca 861; Seca Ltd., Vogel & Halke, Hamburg, Germany) with an accuracy of 0.1 kg and a stadiometer (Seca Leicester Height Measure; Seca Ltd., Vogel & Halke) to the nearest 0.1 cm, respectively, with the participant in light clothing and with no shoes. BMI was calculated as weight (kg) divided by height squared (m^2). Waist circumference (WC) was measured using an inelastic plastic tape, which was applied in the area between the lower margin of the last rib and the crest of the ilium at the level of the umbilicus, and gluteal circumference (GC), at the level of the greater trochanters and pubic symphysis to the nearest 0.1 cm. Right triceps, biceps (BSKF), subscapular, and suprailiac skinfolds were measured using a Lange skinfold caliper. All these procedures were performed by a single, well-trained researcher.

Body composition (FM and FFM) was determined by DXA (Lunar DPX-MD, Madison, WI; coefficient of variation, 2% and 1.1% for FM and FFM, respectively) by means of the analysis version 4.6 software. Furthermore, a medium scan mode was used, unless a slower mode was suggested by the manufacturer, for obese participants. A daily quality assurance check was performed, as suggested by the manufacturer. The scans were performed in the morning by an experienced technician.

Physical activity was assessed by recording the number of daily steps for 1 week as measured by pedometers (Yamax, Digi-Walker, SW 200), as validated and described elsewhere.[3]

According to the data collected, seven models[4-7] were retrieved from the literature which can be applied to white postmenopausal women, as shown analytically in Table 1.

The normality of continuous variables was evaluated through the Kolmogorov-Smirnov test. Continuous variables are presented as mean (SD). Regarding the model rationale, a multiple linear regression was used to develop the models to estimate FM. In particular, the backward stepwise procedure was used to retain the more significant variables (P value for entering a variable was set to 0.05, and P value for removing a variable was set to 0.10). The variables entered in the initial model were WC, GC, all four skinfolds, weight, height, and BMI. Bland-Altman analysis and intraclass correlation coefficient (ICC) were used in the validation cohort to validate the formed model against DXA results and compare it to the retrieved models as they were validated to DXA as well. Any differences between the development and validation cohorts, methods, bias, and its statistical significance were checked with a paired-samples t test against DXA results. Statistical significance was set to $P = 0.05$. All statistical calculations were performed using SPSS version 14.0 software (SPSS Inc., Chicago, IL).

RESULTS

Physical activity was 6,499 (3,001) steps for the development cohort and 6,600 (3,394) steps for the validation cohort, with no significant difference ($P = 0.801$).

The multiple linear regression model consisted of the following variables: GC, BMI, and BSKF. In particular, the generated equation was as follows:

$$\mathrm{FM} = 0.069 \times \mathrm{BSKF} + 0.553 \times \mathrm{W} - 14.655 \times \mathrm{H} + 0.218 \times \mathrm{GC} - 9.830,$$

where FM is fat mass (kg), GC is gluteal circumference (cm), W is weight (kg), H is height (m), and BSKF is biceps skinfold (mm).

The model explained 93.4% of the variance ($r^2 = 0.934$, $P < 0.0001$, and SE of the estimate = 2.14). Then, it was applied to the validation cohort, and the Bland-Altman technique showed a nonstatistically significant bias of 0.158 kg ($P = 0.476$). The limits of agreement were ±4.21 kg (SD, ±2.1 kg), indicating acceptable validity. The model's validity was further checked upon BMI ranges and age groups of older and younger than 65 years. More specifically, BMI less than 25, 25-30, and more than 30 kg/m^2 yielded a nonstatistically significant bias of −0.379 kg ($P = 0.290$), −0.282 kg ($P = 0.383$), and −0.499 kg ($P = 0.232$), respectively, with limits of agreement of ±2.94, ±3.88, and ±4.92 kg and ICCs of

TABLE 1. *Validation and comparison of models in cohort 2 (n = 91)*

Study	Reference method	Model	Age, y	n	Bias	Limits of agreement	Significance of bias	ICC	r^a
Martarelli et al (2008)	BIA	FM = 1.9337 × BMI − 26.422	11-80	341	-1.239^b	6.877	0.001	0.956	0.131
Noppa et al (1979)	Tritiated water, TBK	BF = 0.37 × W + 0.13 × WC + 0.10 × (BSKF + TSKF) − 21.1	44-66	227	-6.997^b	6.197	0.001	0.951	-0.718^b
Lean et al (1996)	Underwater weighing	%BF = 0.232 × WC + 0.657 × TSKF + 0.215 × AGE − 5.5	18-64	84	3.372^b	8.052	0.001	0.945	0.307^c
Lean et al (1996)	Underwater weighing	%BF = 0.73 × BMI + 0.548 × TSKF + 0.27 × AGE − 5.9	18-64	84	3.424^b	7.405	0.001	0.955	0.374^b
Visser et al (1994)	Underwater weighing	BD = 0.0186 × sex − 0.030 × log(BSKF + TSKF) + 1.0481 (♀: 0, ♂: 1)	60-87	128	1.621^b	6.156	0.001	0.951	-0.729^b
Visser et al (1994)	Underwater weighing	BD = 0.0226 × sex − 0.0022 × BMI + 1.0605 (♀: 0, ♂: 1)	60-87	128	2.748^b	5.246	0.001	0.976	0.306^c
Visser et al (1994)	Underwater weighing	BD = 0.0212 × sex − 0.0356 × log(BSKF + TSKF+ SupSKF + SubSKF) + 1.0688 (♀ :0, ♂: 1)	60-87	128	1.152^b	6.233	0.001	0.951	-0.695^b
Current study	DXA	FM = 0.069 × BSKF + 0.553 × W − 14.655 × H + 0.218 × GC − 9.830	47-79	185	0.158	4.206	0.476	0.983	0.033

ICC, intraclass correlation coefficient; BIA, bioelectrical impedance analysis; FM, fat mass; BMI, body mass index; TBK, total body potassium; BF, body fat; W, weight; WC, waist circumference; BSKF, biceps skinfold; TSKF, triceps skinfold; %BF, percentage body fat; BD, body density; SupSKF, suprailiac skinfold; SubSKF, subscapular skinfold; H, height; GC, gluteal circumference; DXA, dual-energy x-ray absorptiometry; ♀, female; ♂, male.

[a] Correlation coefficient of difference to mean from the Bland-Altman plot.

[b] $P < 0.001$.

[c] $P < 0.05$.

0.935, 0.892, and 0.957, respectively. Regarding the age bias, it amounted to −0.072 kg (P = 0.762) and −0.330 kg (P = 0.482), with limits of agreement of ±3.72 and ±5.06 kg and ICCs of 0.988 and 0.971, for women older and younger than 65 years, respectively. Furthermore, it was not shown to overestimate or underestimate FM in the range of FM. Finally, the correlation observed between the average and the difference was statistically insignificant (P = 0.078, r = −0.130). The Bland-Altman analysis is shown in Figure 1. Table 1 illustrates the models retrieved from the relevant bibliography and their validations of the validation cohort, as well as the validation of the model developed in the current study, in terms of bias, limits of agreement, and the correlations between mean and differences in the Bland-Altman analyses and ICCs.

DISCUSSION

In this study, a simple model was developed for predicting FM using simple anthropometric data in a sample of low to moderately active postmenopausal women and was found to be of acceptable validity and of very low bias. The model explained 93.4% of the variance (r^2 = 0.934), which is considered very high, probably due to the following reasons. First, the simple parameters taken into consideration in the model such as height, weight, BSKF, and GC are less susceptible to measurement error.[8] Second, the model was formed upon an adequate sample size and a homogeneous group with regard to age and sex compared with the other models tested (Table 1). More analytically, the models of Lean et al[6] and Martarelli et al[5] were structured on a sample with a wide age range, whereas the model of Visser et al[7] was derived from a sample consisting of volunteers of both sexes. On the other hand, the equation of Noppa et al,[4] despite being formed from a rather adequate sample size and being age and sex specific, significantly underestimated the FM parameter probably because it had been based on Swedish women of apple-shaped body type, thus applying WC as an independent variable. Furthermore, different reference

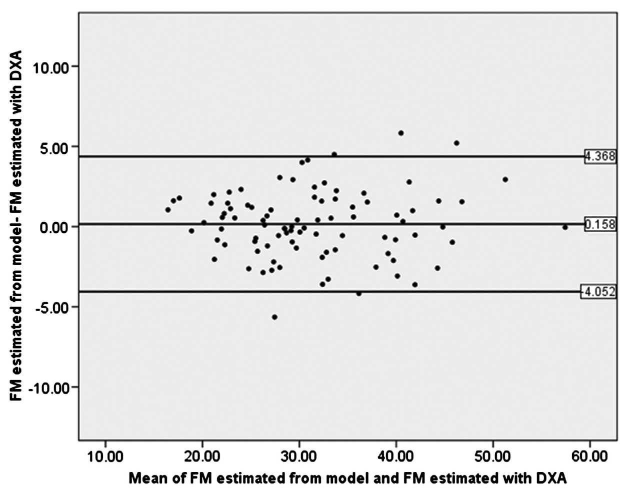

FIG. 1. Bland-Altman plot for the developed model. FM, fat mass; DXA, dual-energy x-ray absorptiometry.

methods used for the development of the tested equations might have resulted in lower performance in this study.

The developed model performed well, compared with the retrieved models. It had the highest ICC (0.983), was found to be unbiased, and had the narrowest limits of agreement (±4.21 kg). All models were found to be quite precise according to ICC, yet they were found to have a significant bias varying from −1.239 to −6.996 kg and limits of agreement ranging from ±5.25 to ±8.05 kg. Furthermore, the models of Noppa et al and Visser et al, based on skinfolds, were found to significantly underestimate FM as this increased, with $r = -0.718$, -0.729, and -0.695, respectively (Table 1). The rest of the models significantly overestimated FM, except that of Martarelli et al, which had very low correlation coefficient.

An important limitation of skinfold measurement in this population is that not all sites of skinfold measurements are easily accessed because women at this age usually feel uncomfortable with the procedure of exposing specific body parts. Therefore, only a limited selection of four sites was made. Other sites, such as the thighs, could provide additional data and would allow the checking of the validity of an extended number of equations in this cohort. This limitation, though, also functions as an advantage for this target population because only the least invasive biceps skinfold is required.

CONCLUSIONS

In conclusion, it could be suggested that the model derived from the current work was found to be accurate, valid, and potentially applicable to clinical practice and research. The model's accuracy and reliability remained significant also when tested in different levels of BMI, ranging from 20.5-42 valid kg/m^2. Further validation of this model in similar and potentially larger populations is expected to provide stronger evidence concerning its accuracy. The validation of this model's accuracy to detect prospective changes in FM after an intervention period is considered to be the next step for further support of its use in clinical practice.

Acknowledgments: The authors would like to thank Alexandra Koumpitski, Paraskeui-Eirini Siatitsa, Aikaterini Kyriakou, Vasiliki Dede, and Anastasia Vandorou for their contributions to the data collection.

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