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Prediction equations for the estimation of body composition in the elderly using anthropometric data

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To study the relationship between health and nutritional status in elderly populations, information about body composition is essential. To collect this information in large epidemiological studies, practical methods based on anthropometric data must be available. In the present study the relationship between body composition, determined by densitometry, and anthropometric data in 204 elderly men and women, aged 60–87 years, was analysed. Existing prediction equations described in the literature, and mainly based on young and middle-aged subjects, generally underestimated percentage body fat in the elderly study population. Therefore, new prediction equations were developed, based on sex and the sum of two (biceps and triceps) or four (biceps, triceps, suprailiaca and subscapula) skinfolds or the body mass index (BMI). Addition of age or body circumferences to the models did not improve the prediction of body density. Internal cross validation and external validation revealed that the formulas are valid for the estimation of body density in elderly subjects. The standard errors of estimate of the three models, expressed as percentage body fat, were 5·6, 5·4 and 4·8% respectively.

Body composition: Anthropometric measurement: Elderly

The number of elderly people is increasing in industrialized countries as well as in developing countries. Information about health status, and especially factors influencing health in old age, is therefore needed. Various studies have shown a relationship between health and nutritional status in the elderly. While studying this relationship, information concerning body composition is indispensable (Chumlea & Baumgartner, 1989; Kuczmarski, 1989). Body-fat content and distribution in elderly subjects seem to be related to risk factors for cardiovascular disease such as high blood pressure (Löwik *et al.* 1991; Kubena *et al.* 1991), lower plasma high-density-lipoprotein (HDL)-cholesterol and higher plasma triacylglycerol concentrations (Chumlea *et al.* 1992) and diabetes (Kaye *et al.* 1991; Kubena *et al.* 1991). Underweight and undernutrition in old age are found to be related to higher mortality rates (Mattila *et al.* 1986; Volkert *et al.* 1992).

To study the effect of body composition on morbidity and mortality, large epidemiological studies are requisite. However, commonly used methods for the assessment of body composition such as densitometry are difficult to perform in elderly subjects and are not suitable for field studies. Apart from that, the densitometric method also has its limitations in elderly subjects as the assumptions underlying this method, i.e. a density of the fat mass of 0·900 kg/l and a density of the fat-free mass of 1·100 kg/l, may be incorrect for elderly subjects (Deurenberg *et al.* 1989*b*). Body composition predicted from relatively simple anthropometric measures is more practical.

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Various prediction formulas for content of body fat based on skinfolds (Durnin & Womersley, 1974; Noppa *et al.* 1979; Heitman, 1990), body mass index (BMI) (Womersley & Durnin, 1977; Norgan & Ferro-Luzzi, 1982; Garrow & Webster, 1985; Heitman, 1990; Deurenberg *et al.* 1991) or both (Svendsen *et al.* 1991) have been described in the literature. However, these formulas were mostly developed in young and middle-aged populations (Norgan & Ferro-Luzzi, 1982; Garrow & Webster, 1985; Heitman, 1990; Deurenberg *et al.* 1991); or rather small groups of elderly (Durnin & Womersley, 1974; Womersley & Durnin, 1977; Noppa *et al.* 1979; Svendsen *et al.* 1991).

Both cross-sectional and longitudinal studies show that body composition changes with age. The amount of fat in the body generally increases and relatively more fat is accumulated internally (Borkan & Norris, 1977; Schwartz *et al.* 1990; Carmelli *et al.* 1991). Stature decreases with increasing age due to senile kyphosis and shortening of the spinal vertebrae (Kucsmarski, 1989). Therefore, prediction formulas developed in young and middle-aged subjects based on skinfolds, weight, height or the BMI, are not likely to be valid in elderly subjects.

The aim of the present study was to investigate the relationship between body density and anthropometric measurements in a large group of elderly men and women, aged 60 to 87 years of age.

SUBJECTS AND METHODS

Subjects

The study population was composed of 204 apparently healthy elderly subjects, 128 women and seventy-six men, aged 60–87 years. The subjects were recruited by advertisements in local newspapers and by visiting homes and clubs for the elderly in the surroundings of Wageningen. All subjects completed a medical questionnaire which was checked by a physician. Subjects taking diuretic drugs that could influence body composition or the state of hydration, and heavy smokers (> 10 cigarettes/d) were excluded from the study. The experimental procedures were approved by the Ethical Committee of the Department of Human Nutrition. Characteristics of the subjects are given in Table 1. For external validation the data of twenty-three elderly people, aged 62–82 years, were used. These subjects were measured at the Department of Human Biology, University of Limburg, using the same methodology.

Body composition

Anthropometric measurements and the measurement of body density were performed on the same day. Body weight was measured to the nearest 0·05 kg using a digital scale (ED60-T; Berkel, Rotterdam, The Netherlands). Body height was measured by means of a microtoise to the nearest 0·001 m. BMI was calculated as body weight (kg) divided by height (m) squared.

Body density was determined by underwater weighing to the nearest 0·001 kg (3826MP 81; Sartorius, Göttingen, Germany) with simultaneous determination of the lung volume by a helium dilution technique (Spiro-Junior; Jaeger GmBH, Würtzburg, Germany). The measurement was carried out in duplicate if possible. Body fat content (%) was calculated from density using Siri's formula (Siri, 1961).

Skinfolds

Skinfolds were measured at the left side of the body to the nearest 0·002 m with Harpenden skinfold callipers (Holtain Ltd, Bryberian, Crymmych). The skinfolds were measured in triplicate at the following sites: (1) triceps, halfway between the acromion process and the olecranon process; (2) biceps, at the same level as the triceps skinfold, directly above the

Table 1. *Subject characteristics*

	Women (n 128)		Men (n 76)	
	Mean	SD	Mean	SD
Age (years)	70·2	5·3	71·0	5·9
Body weight (kg)	68·1	9·5	76·5***	9·6
Body height (m)	1·616	0·061	1·752***	0·071
Body mass index (kg/m²)	26·1	3·6	24·9**	2·6
Density (kg/l)	1·0037	0·0124	1·0289***	0·0119
Body fat content (%)†	43·3	6·1	31·2***	5·6
Triceps (mm)	19·8	5·1	12·5***	3·3
Biceps (mm)	11·8	4·5	6·4***	2·2
Subscapula (mm)	19·8	7·5	17·4**	5·5
Suprailiaca (mm)	19·8	8·0	17·9	6·2
Para-umbilica (mm)‡	25·7	7·7	20·7***	6·2
Quadriceps (mm)§	32·5	7·1	16·5***	6·6
Fibula (mm)‖	15·3	6·0	7·4***	2·8

Significantly different from women; ** $P < 0·01$, *** $P < 0·001$.
† Calculated using Siri's formula.
‡ 125 women, seventy men.
§ Sixty-two women, thirty-nine men.
‖ Fifty-nine women, thirty-three men.

centre of the cubital fossa; (3) sub-scapula, about 20 mm below the tip of the scapula, at an angle of 45° to the lateral side of the body; (4) suprailiaca, just above the ilia crest, in the axillary line; (5) para-umbilica, at one-third of the distance between the umbilicus and the lateral side of the body; (6) quadriceps, halfway between the ilia crest and the patella in a vertical line; (7) fibula, on the fibula at the level of the greatest circumference. The para-umbilica, quadriceps and fibula were only measured in a subgroup of the population. The average value of the triplicate measurements was used in the statistical analysis. All skinfolds, and the sums of skinfolds, were $\log_{10}$ transformed to correct for a skewed distribution.

Statistical methods

Correlations between body density and other body composition variables were calculated using Pearson's product-moment correlations. Differences between density from under-water weighing and density predicted from skinfolds or BMI equations were tested with paired Student's t tests. Stepwise multiple regression analysis was used with density as the dependent variable and sex, age, BMI or (sums of) skinfolds as independent variables. Prediction equations were developed in two groups (randomly assigned by a computer program) of the total population. Internal cross validation was carried out by testing whether the prediction equation of one group could validly predict density in the other group. The prediction equation based on the total study population was applied to body composition data from another group of Dutch elderly subjects to validate the equation externally. Two-sided P values were considered statistically significant at $P < 0·05$. Results are expressed as means with their standard deviations (SD).

RESULTS

Table 1 shows some characteristics of the subjects. All variables, except age and the suprailiaca skinfold, were statistically different between the sexes. Men were taller and had

Table 2. *Differences between body fat content (%) predicted from various equations in the literature and estimated by densitometry using Siri's (1961) formula (difference = predicted − estimated)*

	Women		Men	
	Mean	SD	Mean	SD
Estimated from densitometry:	43·3	6·1	31·2	5·6
Difference when predicted from skinfolds:				
Durnin & Womersley (1974)	−6·0***	5·9	−4·1***	5·6
Noppa *et al.* (1979)	−12·7***	5·3	—	—
Heitman (1990)	−19·8***	5·8	−13·9***	5·4
Difference when predicted from BMI:				
Womersley & Durnin (1977)	−8·3***	4·8	−5·2***	4·8
Norgan & Ferro-Luzzi (1982)	—	—	−9·2***†	4·8
	—	—	−0·5‡	4·5
Garrow & Webster (1985)	−10·0***	5·0	−8·8***	5·6
Heitman (1990)	−9·2***	5·0	−8·2***	4·9
Deurenberg *et al.* (1991)	−1·2**	5·0	−1·2*	4·5
Svendsen *et al.* (1991)	−14·2***	6·4	−11·8***	5·4

Mean predicted value was significantly different from the estimated value: * $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Equation included BMI only.
‡ Equation included BMI and age.

a higher body weight compared with the women. The body density of the women was lower, resulting in a higher proportion of body fat. Nearly all skinfold thicknesses were larger and BMI was higher in women.

To investigate whether prediction formulas from the literature were able to predict body fat content in this group of elderly subjects, various formulas were applied to the data (Table 2). Nearly all formulas significantly underestimated the percentage body fat in this population. Prediction errors of body fat percentage ranged from −19·8% to −1·2% in women and from −13·9% to −0·5% in men.

Because of the large mean differences between predicted and measured body fat contents, new prediction formulas were developed using skinfolds, BMI, sex and age as independent variables.

In Table 3 the correlation coefficients between body density and several skinfolds and BMI are shown. In women all skinfolds were significantly correlated with body density. In men no correlation was found between body density and the para-umbilica skinfold, the quadriceps skinfold and the fibula skinfold. Generally, both in men and women, the skinfolds on the trunk were more highly correlated with body density than the skinfolds on the extremities, except for the umbilica skinfold in men. The correlation of body density and BMI was higher than any correlation of the body density with skinfolds, in both males and females.

After the total study population was randomly assigned into two groups, prediction equations for body density were developed in each subgroup using multi-linear regression techniques. Group 1 consisted of 109 subjects, seventy-four women and thirty-five men, while group 2 consisted of ninety-five subjects, fifty-four women and forty-one men. The results of three models in each group are shown in Table 4. The regression model with the highest explained variance (R^2) and the lowest prediction error (standard error of estimate, SEE) in both subgroups contained gender and BMI as independent variables. The best

Table 3. *Pearson's product-moment correlation coefficients between body density and (the sum of) skinfolds (mm) or the body mass index (kg/m²) in elderly men and women*

Skinfold†	Women	Men
Triceps	−0·28**	−0·26*
Biceps	−0·27**	−0·29*
Subscapula	−0·39***	−0·33**
Suprailiaca	−0·43***	−0·37***
Para-umbilica‡	−0·42***	−0·07
Quadriceps§	−0·40**	−0·19
Fibula‖	−0·28*	−0·18
Sum of 2	−0·29**	−0·31**
Sum of 4	−0·40***	−0·38***
Body mass index	−0·61***	−0·52***

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Skinfolds were $\log_{10}$ transformed; sum of 2 = $\log_{10}$ (biceps + triceps); sum of 4 = $\log_{10}$ (biceps + triceps + subscapula + suprailiaca).
‡ Values from 125 women and seventy men.
§ Values from sixty-two women and thirty-nine men.
‖ Values from fifty-nine women and thirty-three men.

Table 4. *Multiple linear regression of body density against sex, skinfold thickness and body mass index in the two random groups and in the total population*

(Regression coefficients with their standard errors)

	Group 1 (*n* 109)		Group 2 (*n* 95)		Total (*n* 204)	
	Coeff	SE	Coeff	SE	Coeff	SE
Model 1						
Sex†	0·0183*	0·0033	0·0189	0·0031	0·0186	0·0023
Log_{10}(sum of 2)‡	−0·0359	0·0103	−0·0248	0·0092	−0·0300	0·0069
Intercept	1·0567	0·0151	1·0406	0·0137	1·0481	0·0102
R^2	0·54		0·56		0·55	
SEE	0·0121		0·0114		0·0117	
Model 2						
Sex†	0·0213	0·0025	0·0213	0·0025	0·0212	0·0018
Log_{10}(sum of 4)‡	−0·0440	0·0087	−0·0281	0·0080	−0·0356	0·0059
Intercept	1·0842	0·0160	1·0551	0·0149	1·0688	0·0109
R^2	0·58		0·58		0·58	
SEE	0·0115		0·0111		0·0113	
Model 3						
Sex	0·0223	0·0021	0·0226	0·0021	0·0226	0·0015
Body mass index	−0·0026	0·0003	−0·0018	0·0003	−0·0022	0·0002
Intercept	1·0704	0·0084	1·0517	0·0079	1·0605	0·0057
R^2	0·68		0·66		0·67	
SEE	0·0101		0·0099		0·0100	

R^2, explained variance; SEE, standard error of estimate.
* All independent variables contribute significantly to the models ($P < 0·01$).
† Sex, 0 for women, 1 for men.
‡ Sum of 2, biceps + triceps (mm); sum of 4, biceps + triceps + subscapula + suprailiaca (mm).

Table 5. *Internal cross validation of the three equations developed for the prediction of body density and body fat content in the two random groups (difference = measured − predicted)*

(Mean values and standard deviations)

	Group 1 (*n* 109)		Group 2 (*n* 95)	
Method used	Mean	SD	Mean	SD
Density (kg/l)				
Densitometry	1·0120	0·0176	1·0143	0·0169
Predicted using model 1	1·0117	0·0117	1·0147	0·0139
Difference	0·0003	0·0121	−0·0005	0·0114
Predicted using model 2	1·0114	0·0120	1·0152	0·0145
Difference	0·0006	0·0115	−0·0009	0·0113
Predicted using model 3	1·0122	0·0131	1·0139	0·0153
Difference	−0·0002	0·0102	0·0004	0·0102
Body fat content (%)				
Densitometry	39·27	8·47	38·17	8·09
Predicted using model 1	39·28	5·87	38·03	6·33
Difference	−0·01	5·80	0·14	5·42
Predicted using model 2	39·37	6·05	37·94	6·50
Difference	−0·10	5·51	0·23	5·32
Predicted using model 3	39·17	6·61	38·20	6·97
Difference	0·11	4·84	−0·03	4·76

regression model using skinfolds contained the variables sex and the $\log_{10}$ transformed sum of biceps, triceps, subscapula and suprailiaca. However, a model based on sex and the $\log_{10}$ transformed sum of only the triceps and biceps skinfold had only a slightly lower explained variance and a comparable prediction error. Age did not contribute to the explained variance in either subgroup.

Internal cross validation revealed that the prediction equation developed in one subgroup could validly predict body density in the other subgroup (Table 5). Therefore, the data from the groups could be combined (Table 4). The correlation coefficients between measured and predicted densities in group 1 and group 2 were 0·73 and 0·74 respectively using model 1, 0·76 and 0·76 respectively using model 2, and 0·82 and 0·81 respectively using model 3 (all $P < 0{\cdot}0001$). The SEE in body density of the models varied from 0·01 to 0·0117 kg/l, resulting in a prediction error of about 5% body fat at a body density of 1·0030 kg/l.

External validation of the developed prediction formulas was carried out using the body composition data from an independent sample of twenty-three elderly subjects. The main characteristics of this population are presented in Table 6. The suprailiaca skinfold and the subscapula skinfold were not measured in this population. Therefore, prediction model 2, using the sum of four skinfolds, could not be validated. Body density of these elderly subjects, predicted by model 1 and model 3, was not significantly different from the measured value (Table 6). The differences were −0·0072 and −0·0054 kg/l for the two models respectively in women, and −0·0011 and −0·0055 kg/l respectively in men. When these values were expressed as percentage body fat the differences were +3·5 (SD 7·3) and +2·5 (SD 5·9)% in women, and +0·5 (SD 5·3) and +2·5 (SD 5·2)% in men.

Table 6. *External validation; population characteristics, the difference (difference = measured−predicted) and the Pearson's correlation coefficients between predicted and measured body density and body fat content*

(Mean values and standard deviations)

Subjects...	Women (n 11)		Men (n 12)	
	Mean	SD	Mean	SD
Age (years)	73·3	5·7	68·8	4·3
Body weight (kg)	66·7	6·0	79·8	7·2
Body height (m)	1·561	0·052	1·709	0·059
Body mass index (kg/m^2)	27·4	1·9	27·3	2·0
Sum of biceps and triceps (mm)	44·4	11·1	20·2	5·3
Density (kg/l)				
Measured	1·0063	0·0147	1·0291	0·0120
Difference using prediction model 1	−0·0072	0·0151	−0·0011	0·0114
Correlation coefficient	0·01		0·33	
Difference using prediction model 3	−0·0054	0·0121	−0·0055	0·0111
Correlation coefficient	0·71*		0·39	
Body fat content (%)				
Measured	42·00	7·18	31·05	5·63
Difference using prediction model 1	3·48	7·34	0·46	5·34
Correlation coefficient	0·01		0·33	
Difference using prediction model 3	2·54	5·91	2·51	5·20
Correlation coefficient	0·71*		0·39	

* $P < 0·05$.

DISCUSSION

The subjects in the present study were volunteers recruited in the surroundings of Wageningen. The sample is therefore not representative of the elderly in The Netherlands. However, comparison of weight and height of the study sample with data from the Central Bureau of Statistics revealed that the study sample was not very different from the general elderly population (aged 60 years or more) in The Netherlands (males: 76·6 kg, 1·747 m, females: 68·3 kg, 1·644 m; Centraal Bureau voor de Statistiek, 1992). The BMI and body composition data are also comparable with data from other studies carried out on the elderly in The Netherlands (de Groot *et al.* 1991; Minten *et al.* 1991).

When prediction equations from the literature were applied to the study sample nearly all equations underestimated body fat content. The equations including age as an independent continuous variable (Norgan & Ferro-Luzzi, 1982; Deurenberg *et al.* 1991) showed the most accurate prediction of percentage body fat. The other equations from the literature which were generally developed using young to middle-aged subjects largely underestimated body fat content. Of these equations the equation of Durnin & Womersley (1974), based on skinfold thickness, showed the best result. When comparing the body fat content of the subjects in the studies of Noppa *et al.* (1979) and Svendsen *et al.* (1991), it is remarkable that they are much lower compared with those observed in the present study, the study of Durnin & Womersley (1974) and the study of Womersley & Durnin (1977). The BMI of the subjects of the study of Svendsen *et al.* (1991) is, however, comparable with the present study but body fat, determined by dual-energy X-ray absorptiometry, is much lower. These authors suggested that population specificity may have caused the large differences. It seems unlikely that differences between the Danish population and the Dutch population are the basis of these large differences. Differences in body fat content between populations are more likely to be caused by age differences and/or the different methods used to estimate body fat (Blanchard *et al.* 1990; Baumgartner *et al.* 1991; Johansson *et al.* 1993).

The skinfold thickness that was best correlated with body density in both elderly men and women was the suprailiaca. A prediction model for body density based on this single skinfold and sex had an explained variance of 59% and a SEE of 0·0112 kg/l. Despite the fact that this model was comparable with the model using sex and the sum of four skinfolds, this model was not evaluated further. A prediction formula based on only one skinfold will lead to considerable errors when the skinfold is measured inaccurately or when the subjects have an unusual subcutaneous fat distribution. Therefore, only models based on more than one skinfold were investigated. Models based on sex and the sum of skinfolds had higher explained variances and lower SEE than sex-specific models or models based on separate skinfolds (results not shown). Since there was no interaction between sex and the sum of skinfolds (or sex and BMI) in the elderly population, only one single prediction model was developed for both sexes combined, adding sex as a dummy variable. The model with sex and the sum of triceps, biceps, subscapula and suprailiaca as independent variables predicted body density in the elderly slightly better (R^2 0·58, SEE 0·0113 kg/l) compared with a model using sex and the sum of the triceps and biceps skinfold (R^2 0·55, SEE 0·0117 kg/l). A model based on these two skinfolds has several practical advantages. The biceps and triceps skinfolds are relatively easy to measure, even when the elderly subject is confined to a wheelchair or is bedridden. Furthermore, subjects do not need to undress which is especially practical in field studies.

The best prediction of body density was obtained using sex and BMI as independent variables (R^2 0·67, SEE 0·0100 kg/l).

The SEE values, expressed as percentage body fat, of the models based on sex and two skinfolds, sex and four skinfolds, and sex and BMI were 5·6, 5·4 and 4·8% respectively. These errors are comparable with reported SEE in the prediction of body fat in the literature, which range from 3·5–5·5% in old age groups.

Stature is known to decrease with age due to kyphosis and a shrinkage of the spinal vertebrae (Kuczmarski, 1989). This will affect BMI, and thus the prediction of body density from BMI. Shrinkage of the spinal vertebrae and kyphosis was of course already present in the present study population, thus this effect is already partly corrected for. To evaluate the effect of an underestimation of real stature by 0·05 m, the difference in predicted density from BMI was calculated. An underestimation of stature by 0·05 m results in an overestimation of body fat content of only 1·9 (SD 0·3)% in women and 1·5 (SD 0·2)% in men. Thus, quite a large error in the measurement of stature results only in small errors in predicted body density.

In all models age was not included. Dividing the total study population into subgroups of 5 year intervals revealed no statistically significant differences between predicted and estimated density in any of the age groups. Besides, in the models containing skinfolds, age was not correlated with the residual error. Thus, it seems that the relationship between body density and skinfolds is not dependent on age between 60 and 87 years. The residual error of model 3 was slightly but significantly correlated with age (r −0·15, $P = 0{\cdot}03$). Age significantly contributed to this model which contains sex and BMI. However, including age as independent variable in this model increased the explained variance by only 1% and decreased the SEE by 0·0001 kg/l. Because of the minor decrease in prediction error and the fact that no difference between predicted and estimated body density was found in any of the 5-year age groups, age was left out of the equation.

The use of body circumferences for the prediction of body fatness in the elderly has frequently been suggested by several authors (Young *et al.* 1963; Chumlea *et al.* 1984; Minten *et al.* 1991). In the present study circumferences of mid-upper arm, waist, hip and thigh were also measured and related to body density (results not shown). In women the hip circumference (r −0·56, $P = 0{\cdot}0001$), and in men the waist circumference (r −0·58, $P = 0{\cdot}0001$) was best correlated with body density. Since there were significant interactions between all circumferences and sex, we investigated whether sex-specific equations containing circumferences were better at predicting body density compared with the models shown in Table 4. The explained variance for the best model containing one or more circumferences was 36% in women (hip and waist circumference) and 28% in men (waist circumference). In the sex-specific models some circumferences contributed significantly to models which already contained the sum of two or four skinfolds. However, the SEE of these models, which ranged from 0·0098 to 0·0116 kg/l, were comparable with the SEE of the three models in Table 4, and thus did not really improve the prediction of body density. Durnin & Womersley (1974) also reported that complex equations, including skinfolds and several limb circumferences, resulted in only minimal increases in accuracy compared with equations based on skinfolds only. It was concluded that prediction equations using circumferences (together with other anthropometric measures) have no advantages over equations using only skinfolds or BMI. Difficulties in the measurement of circumferences due to a reduced elasticity of the skin and the abdominal wall in elderly subjects may be responsible.

As a reference method in the present study, hydrodensitometry was used. Despite the fact that Siri's formula (Siri, 1961) is generally used to calculate body fat content in elderly subjects, it is questionable whether this is correct. With increasing age the density of the fat-free mass may decrease due to demineralization of the bone and changes in body water. Using a two-compartment model with the assumption that the density of the fat-free mass is 1·100 kg/l could result in a systematic overestimation of body fat content in elderly subjects by 1–2% (Deurenberg *et al.* 1989*b*). Moreover, with increasing fatness the relative amounts of minerals and protein in the fat-free mass may decrease (Deurenberg *et al.* 1989*a*). Therefore, in elderly people calculation of body fat content from body density needs some care. Baumgartner *et al.* (1991) investigated the difference in estimated body fat content of elderly men and women between a two- and a four-compartment model. The mean difference between the two methods was about 1·7%, and was correlated with the aqueous fraction of the fat-free mass but not with age or with the mineral fraction of the fat-free mass. This suggests that the error in body fat made by using a two-compartment model depends predominantly on the hydration of the fat-free mass. Based on the calculations of Deurenberg *et al.* (1989*a*, *b*), adjustments can be made to Siri's formula. Therefore, body density, used as a dependent variable in the present study, can be used in the adjusted or unadjusted Siri's formula to calculate body fat content. It remains that at an individual level, even after any adjustment of Siri's formula, an error of about 3% body fat is possible using the hydrodensitometric method (Siri, 1956; Lohman, 1981).

The prediction formulas developed in the present study, based on BMI or the sum of two or four skinfolds, were internally cross validated and also externally validated in an independent sample. These procedures revealed that the formulas are valid for the estimation of body fat content in groups of elderly subjects. As with all prediction equations, one should always be cautious when applying the formula to elderly populations that are substantially different from the present study. Individual values should always be interpreted cautiously.

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