Measurement of Body Fat in Healthy Elderly Men: 
A Comparison of Methods

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Background. Nutritional evaluation of elderly people is of great importance. Two-component methods for body composition assessment, such as anthropometry and bioelectrical impedance (BIA), are widely used in clinical practice, but their fundamental assumptions may be invalid in older people. Dual-energy X-ray absorptiometry (DXA) is a relatively new method for reliable and direct measurements of body mass in its three basic components: total body bone mineral content (TBBMC), mineral free lean tissue mass (LTM), and fat. In this study, percent body fat (%BF) estimates from anthropometry and BIA in men of various ages were compared with corresponding measurements by DXA.

Methods. Body fat percentage was estimated in 67 men aged 20-95 by anthropometric measurements (skinfold thickness, body mass index, or BMI), BIA, and DXA. Age-specific equations were used for anthropometry and BIA. Limits of agreement were calculated between DXA and the other methods.

Results. The equations based on BMI and BIA systematically overestimated %BF with respect to %BF measured by DXA in people of all ages. Intermethod difference between DXA and skinfold thicknesses was less marked, but in over-80-year-olds %BF predicted by skinfold measurements underestimated %BF measured by DXA. Interindividual and age-related variation in TBBMC and in fat-free mass mineralization could partly explain the intermethod differences found between DXA and the other methods.

Conclusions. Because of practical constraints, anthropometry and BIA are often the only available options for body composition assessment in clinical routine; therefore, further research on the validity and improvement of these methods in older people is indicated.

Significant changes in body composition that have important effects on physical function, overall health status, and pharmacokinetics processes occur with age (1,2). Therefore, accurate and reliable measurements of body composition in elderly people are desirable. Anthropometric measurements and bioelectrical impedance (BIA) are the least expensive and simplest available methods for body composition determination; it is questionable, however, whether they can be used with effectiveness and reliability in elderly people, because both methods have a two-component approach to body composition. In the two-component model, the human body consists of two chemically distinct components, fat and fat-free mass (FFM), whose composition and densities are considered to be relatively constant (3). The general applicability of this model, however, is limited by racial (4), age-related (5), and interindividual (6) variability in FFM mineralization. Even underwater weighing, which among the currently used methods to assess body composition continues to be considered the gold standard, is based on the assumptions of the two-component model and does not escape its theoretical limitations. Moreover, buoyancy methods can be stressful and difficult to perform for older persons and are not suitable for field studies.

In recent years, advances in technology have permitted the construction of models of body composition that define the body in terms of more than two components. Dual-energy X-ray absorptiometry (DXA) is very appealing for the noninvasive measurement of body composition in a clinical setting, because it directly measures bone, fat, and lean mass with very high precision and a low radiation dose (7). Detailed characterization of the differences between DXA and currently used two-component methods in subjects of different ages, however, is virtually absent. Thus, the aims of this study were as follows: (a) to assess the ability of DXA, BIA, and anthropometry to predict body fat percentage (%BF) in a sample of healthy men 20 to 95 years old, representative of community-dwelling males in a Northern Italian region, by using statistical methods that assess the degree of agreement between methods; and (b) to assess whether age and variations in FFM mineral content independently influence intermethod differences.

Materials and Methods

Subjects.—The participants were 67 men aged 20–95 living in the Northern Italian region Emilia Romagna. All were in good health, community-dwelling, and free of disease that might have been relevant to consideration of body composition (diagnosis of osteoporosis, renal or hepatic disease, malignancy, cardiovascular disease). Those with unusual diets or physical activities, smokers, or those tak-
ing prescription medications were excluded. Physical examination, routine blood studies, and urine analysis confirmed good health. Informed consent was obtained from all subjects prior to participation.

**Body components.**—The body consists of mineral-free soft tissue and bone (total body bone mineral content, TBBMC). Mineral-free soft tissues are divided into body fat (BF) and mineral-free lean tissue mass (LTM). DXA measures these three components separately. The term fat-free mass (FFM) in this study corresponds to the sum of LTM and TBBMC. BIA and anthropometry measure only two components separately, namely, BF and FFM.

**Anthropometry.**—With the subjects wearing light indoor clothes and no shoes, body weight (BW) was measured to the nearest 0.1 kg and height (H) to nearest 0.5 cm. Body mass index (BMI) was also calculated for all subjects as BW (in kilograms) divided by H (in meters) squared. Skinfold thickness was measured on the right side of the body at four different locations (biceps, triceps, subscapular, and suprailiac folds) with a Harpenden caliper (Holtain Ltd, Bryherian, Crymmych, UK) with the subjects relaxed in a recumbent position. All skinfold-thickness measurements were done in triplicate to the nearest 0.1 mm by the same investigator. The mean value of the three measurements was used in the calculations. Waist and hip circumferences were measured with a tape measure to the nearest 0.5 cm. The ratios of subscapular to triceps skinfold thickness (SS/TS) and the waist-to-hip circumference (WHR) were calculated as indicators of fat distribution. Measurements of skinfold thicknesses and waist and hip circumferences were carried out in accordance with the Lohman manual's instructions (8). Among the various prediction formulas validated in young and middle-aged populations for estimation of %BF from anthropometric measurements, equations including skinfold thicknesses or BMI have been shown to be of practical utility even in elderly people (9). Therefore, we used appropriate gender- and age-specific equations from Durnin and Womersley (10) and from Deurenberg et al. (11) in order to estimate BF% of each subject from the sum of the four skinfold thicknesses and from BMI, respectively.

**Bioelectrical impedance analysis.**—Resistance and reactance were measured by an impedance analyzer (Human-Im, Diestosystem, Milan, Italy) as described by Lukaski et al. (12). Prediction of %BF by BIA was done with sex- and age-specific equations (13,14).

**Dual-energy X-ray absorptiometry.**—Whole-body scans were performed by a model QDR 2000 DXA densitometer, software version 7.10 (Hologic Inc., Waltham, MA). The Hologic QDR 2000 uses a switched pulsed stable dual-energy radiation with two peak kilovoltages of 70 and 140 kVp. For analysis of tissue composition, a step phantom consisting of six fields of acrylic and aluminium of varying thickness with known absorptive properties is scanned in parallel with the subject and serves as an external standard. Analysis of whole-body scans was done using the “enhanced analysis protocol” version 5.64. The composition of soft tissue is given by a ratio of beam attenuation at the lower energy relative to that at the higher energy. Radiation dose of a single measurement is less than 0.1 microGy (7), and scan is completed in less than 20 min. The precision of measurements was 1.6% for FFM, 1.9% for BF, and 1.8% for TBBMC (coefficient of variation calculated from 10 paired measurements).

**Statistical analysis.**—Data are presented as mean (standard deviation [SD]). After testing for normality and equality of variance of the distribution, the significance of difference between means of age groups was tested by parametrical one-way analysis of variance (ANOVA); differences between groups at the 5% significance level ($p < .05$) were assessed by Tukey's post hoc probability test for multiple comparisons. Simple correlations were determined using Pearson's correlation coefficient. Pairwise comparisons between corresponding %BF values from DXA, BMI, and anthropometry were conducted by using paired $t$ tests. The limits of agreement between the three different methods were estimated as the mean intermethod differences ± 2 SD, according to the method described by Bland and Altman (15). To examine whether variation in bone mineral content of FFM influences the intermethod differences for %BF, a multiple linear regression analysis was conducted including age, TBBMC, and TBBMC/LTM as independent variables. The $R^2$ statistic, which measures the proportion of variation in the independent variable that is explained by the regression model, was used as a measure of association between explanatory variables and intermethod differences for %BF. Sigmasstat software was used for the statistical analyses (Jandell Scientific Software, San Rafael, CA).

**RESULTS**

**Descriptive data.**—Descriptive characteristics of the study population subdivided by age groups, and corresponding ANOVA results, are given in Table 1. BMI was significantly higher in subjects of ages 50–59, 60–69, and 70–79 than in subjects below age 50 and over age 80. Weight and height were significantly lower in subjects over age 80 than in subjects below age 50. Regional distribution of fat, as measured by anthropometric indices, did not basically differ between the considered age groups, except for subjects aged 60–69 having a slightly higher WHR than subjects below age 50.

**Body composition.**—Table 2 gives results for one-way ANOVA of body composition estimates from DXA, anthropometry, and BIA by age group. LTM and TBBMC values of men over age 80 were significantly lower than those of the other age groups, but the proportion of lean body mass occupied by the skeleton (TBBMC/LTM) showed no change with age, suggesting a parallel trend for both soft fat-free and bone mineral tissue. BF percentage by DXA of subjects over age 60 was significantly greater than %BF of subjects below age 50. BF percentage from skinfold was significantly greater in subjects in their 60s and 70s than in young subjects below age 50, but no difference was found between subjects over 80 years of age and young subjects...
below age 50. According to BMI and BIA estimates, groups aged 70–79 and 80–89 had a greater %BF than all the younger age groups.

Agreement between DXA, BIA, and anthropometric measurements.—As shown in Table 3, %BF estimates assessed by the four considered techniques (DXA, BIA, skinfold thickness, and BMI) had a high degree of correlation with each other. However, because correlation is an index of association rather than agreement between methods, methodological differences were analyzed on the basis of individual differences in %BF estimates between the various methods (15). Signed mean intermethod differences for %BF with corresponding limit of agreement, referring to the study population as a whole, are presented in Figure 1. The mean ± 2 SD difference is referred to as the limits of agreement and, if the differences are normally distributed, as in our study, it is expected that about 95% of the observations will lie between these limits. Figure 1 confirms that the 95% limits of agreement between all methods were wide. Some distinct biases are also apparent. In particular, it is clear from the figure that BMI method (11) and BIA using age-specific equations (13,14) tended to significantly overestimate %BF relative to DXA (DXA–BMI intermethod difference = −4.522, limits of agreements ± 10.738, p < .001; DXA–BMI intermethod difference = −6.47, limits of agreement ± 15.2, p < .001). Agreement between skinfold thickness (10) and DXA was somewhat better, as indicated by the small intermethod difference (.602, p = .785).

<table>
<thead>
<tr>
<th>Table 1. Characteristics of the Study Groups*</th>
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<tbody>
<tr>
<td>&lt;50 yr (n = 12)</td>
</tr>
<tr>
<td>Age (yr)</td>
</tr>
<tr>
<td>Body weight (kg)</td>
</tr>
<tr>
<td>Height (m)</td>
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<tr>
<td>Body mass index (kg/m²)</td>
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<tr>
<td>Waist-hip ratio</td>
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<td>Subscapular–triceps ratio</td>
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*Mean ± SD. Statistical results from a one-way ANOVA by age group.
†Significantly different from groups <50, 60–69 and 70–79 yr, p < .05. Tukey’s test for multiple comparisons.
‡Significantly different from group <50 yr, p < .05. Tukey’s test for multiple comparisons.
§Significantly different from groups 20–49 and ≥80 yr, p < .05. Tukey’s test for multiple comparisons.

<table>
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<th>Table 2. Body Composition Measurements by DXA, Anthropometry, and BIA in Healthy Males*</th>
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<tr>
<td>DXA</td>
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<tr>
<td>LTM (kg)</td>
</tr>
<tr>
<td>TBBMC (g)</td>
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<tr>
<td>TBBMC/LTM</td>
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<tr>
<td>BF%</td>
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<tr>
<td>Anthropometry</td>
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<tr>
<td>BF% by skinfold thickness (10)</td>
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<td>BF% by BMI (11)</td>
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</table>

*Mean ± SD. Statistical results from a one-way ANOVA by age group. DXA = dual-energy X-ray absorptiometry; BIA = bioimpedance analysis; LTM = lean tissue mass; BF = body fat; TBBMC = total body bone mineral content; BF% = body fat percentage.
†Significantly different from all age groups, p < .05. Tukey’s test for multiple comparisons.
‡Significantly different from groups <50 yr, p < .05. Tukey’s test for multiple comparisons.
§Significantly different from groups <50 and 60–69 yr, p < .05. Tukey’s test for multiple comparisons.

<table>
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<th>Table 3. Correlation Coefficients (r) Between Values of Percent Body Fat Obtained by DXA, Anthropometric Measurements, and BIA in Healthy Males*</th>
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<tbody>
<tr>
<td>DXA</td>
</tr>
<tr>
<td>0.466‡</td>
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<tr>
<td>Skinfold thickness</td>
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</table>

* n = 67. DXA = dual energy X-ray absorptiometry; BIA = bioimpedance analysis; BMI = body mass index. The age-specific equation of Durnin and Womersley (10) was used to predict %BF by skinfold thickness. Deurenberg’s sex–specific equation (11) was used for prediction of %BF by BMI. Deurenberg’s age–specific equations were used for prediction of %BF by BIA (13,14).†p < .001.‡p < .01.
limits of agreement ± 8.4, p < .001), suggesting a systematic underestimation of %BF by skinfold thickness.

As listed in Table 4, multiple linear regression analysis including age, TBBMC, and TBBMC/LTM showed that the three variables explained 33% of the variance of the intermethod difference between %BF by DXA and %BF by BMI; TBBMC and TBBMC/LTM explained 23% of the variance of the intermethod difference between %BF by DXA and %BF by skinfold thickness; TBBMC/LTM alone explained 20% of the variance of the intermethod difference between %BF by DXA and %BF by BIA.

DISCUSSION

DXA is a relatively new method for reliable, safe, practical, and direct measurement of body mass in its three basic components: total body mineral, fat-free mineral-free soft tissue, and fat (7). Scant data are available about the comparison of body composition assessment by DXA in very old people with respect to methods commonly used in clinical practice, such as anthropometry and bioimpedance (5).

Anthropometry and BIA rely on the general assumptions of the two-component model that the densities of fat and fat-free mass are 0.9 kg/L and 1.10 kg/L, respectively (3). Although the two-component model includes techniques such as underwater weighing, traditionally considered the gold standard among all body composition methods, this model can be incorrect for elderly subjects. Indeed, interindividual variation (6) and the aging process itself, with its inherent changes in bone and muscle mass, may induce errors in estimation of %BF when the two-component model is used as the reference method (16).

DXA permits direct measurements of body fat tissue without the assumptions of the two-component model, and may therefore be a better reference method for body composition. We recognize that even DXA cannot assess three components in a truly independent fashion, and assumptions on the distribution of fat are necessary (17). Further, DXA cannot differentiate between body water and lean body mass, and soft tissue analysis algorithms assume that 73.2% of the lean mass is water. As in the two-component model, this is a potential source of errors in the estimate of both lean and fat mass (7). Schoeller (18), in his review of changes in total body water with age, concluded that it is likely that the hydration of FFM increases throughout normal aging, but he assumed that the increase would be small and have little effect on the estimation of body composition in healthy subjects. Although not all authors agree with this (19), we felt that operationally it would be interesting to use the direct DXA assessment as a standard against which the indirect BIA and anthropometric approaches could be evaluated.

The intermethod differences in this study followed a normal distribution; therefore, it is expected that about 95% of the intermethod differences will lie between the limits of agreement (15). Although %BF estimates from all the various methods tended to be highly correlated with each other, the age-specific equations based on BMI and BIA systematically overestimated %BF in subjects over 50 years of age, with the >80-year-olds showing the largest scattering of predicted %BF values. Intermethod difference between

![Figure 1](https://example.com/figure1.png)

Figure 1. Plot of intermethod differences between percent body fat (%BF) values versus their mean values in healthy males (n = 67, age 25–92 y) with limits of agreement according to Bland and Altman (15). The age-specific equation of Durnin and Womersley (10) was used to predict %BF by skinfold thickness. Deurenberg’s sex-specific equation (11) was used for prediction of %BF by BMI. Deurenberg’s age-specific equations (13,14) were used for prediction of %BF by BIA.

but limits of agreement were equally wide (± 12.858). Figure 2 shows the results of calculating the limits of agreement for the three different equations according to each age group. Significantly increasing age-group intermethod differences were found for BMI and BIA age-specific equations starting from age 50. BF percentage by skinfold thickness again showed no systematic differences with respect to DXA in adult and younger elderly subjects until the seventh decade, but in the over-80-year-olds, DXA-skinfold thickness intermethod difference reached significance (4.834,
Figure 2. Plot of intermethod differences between percent body fat (%BF) values versus their mean values in healthy males subdivided by age group, with limits of agreement according to Bland and Altman (15). DXA = dual energy X-ray absorptiometry; BMI = body mass index; BIA = bioimpedance analysis. The age-specific equation of Durnin and Womersley (10) was used to predict %BF by skinfold thickness. Deurenberg’s sex-specific equation (11) was used for prediction of %BF by BMI. Deurenberg’s age-specific equations (13,14) were used for prediction of %BF by BIA. P values refer to paired t test between %BF by DXA and %BF estimates from anthropometric measurements and BIA.
The second is that, reliable as it is, DXA is presently an

gestiging a routine adoption of DXA in geriatric assessment,

however, must be made. The first is that gender differences

methods based on the two-component model. Two points,

mass density may affect the reliability of commonly used

age-related variations in body bone content and fat-free

composition is an essential part of determining an elderly

individual's state of health, especially in the fast-growing

mortality in elders (2, 24). Therefore, quantification of body

body weight and loss of protein (muscle) and adipose stores

are usually associated with increased risk of morbidity and

interpreted this as being due to a selective mortality of

a similar decrease in lean and bone mass. It is well known

at least to some degree, the explanation could be a decreas­

ation of FFM might explain part of the intermethod discrep­

ancies between %BF estimates found in the present study.

In agreement with Wellens et al. (21), individual and age­

related variability in bone mineral content and mineraliza­

tion of FFM might explain part of the intermethod discrepan­

cies between %BF estimates found in the present study.

These results confirm and extend previous suggestions that

application of the two-component model in elderly people

creates the potential for errors and inaccuracies in body

composition measurements (16).

With all the restraints due to the cross-sectional structure

of this study, our data also suggest that %BF as measured

by DXA increases with age, reaching a peak in the mid-60s

and then declines over the following decades, paralleled by

a similar decrease in lean and bone mass. It is well known

that very old people are thin, and many clinicians have

interpreted this as being due to a selective mortality of

obese people. Longitudinal studies, however, suggest that,

at least to some degree, the explanation could be a decreas­ing

degree of fatness in the same individuals (22, 23). Low

body weight and loss of protein (muscle) and adipose stores

are usually associated with increased risk of morbidity and

mortality in elders (2, 24). Therefore, quantification of body

composition is an essential part of determining an elderly

individual's state of health, especially in the fast-growing

segment of the >80-year-olds.

In conclusion, our data showed a great intermethod dis­

crepancy between DXA and other simple noninvasive

methods for determining body composition, such as anthro­

pometry and BIA. This suggests that interindividual and

age-related variations in body bone content and fat-free

mass density may affect the reliability of commonly used

methods based on the two-component model. Two points,

however, must be made. The first is that gender differences

in fat regionalization and rate of age-related bone loss

(3, 23) do not allow the extension of our results to women.

The second is that, reliable as it is, DXA is presently an

expensive and time-consuming method. Rather than sug­

gesting a routine adoption of DXA in geriatric assessment,

we hope for further research on the validity and improve­

ment of anthropometric and BIA methods.

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Table 4. Multiple Linear Analysis for Intermethod Body Composition Differences

Between %BF Estimates Including Age, TBBMC, and TBBMC/LTM*

<table>
<thead>
<tr>
<th>Method</th>
<th>Intercept</th>
<th>Age</th>
<th>TBBMC</th>
<th>TBBMC/LTM</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>DXA less skinfold thickness</td>
<td>-2.210 (7.476)</td>
<td>-3.2 (0.047)</td>
<td>-0.009 (0.002)</td>
<td>590.6 (177.0)</td>
<td>.234</td>
</tr>
<tr>
<td>DXA less BMI</td>
<td>3.889 (5.828)</td>
<td>-1.71 (0.037)</td>
<td>-0.008 (0.001)</td>
<td>579.4 (138.0)</td>
<td>.332</td>
</tr>
<tr>
<td>DXA less BIA</td>
<td>1.736 (9.352)</td>
<td>-2.04 (0.063)</td>
<td>-0.005 (0.003)</td>
<td>471.5 (221.8)</td>
<td>.198</td>
</tr>
</tbody>
</table>

*Values are estimates; SE of estimate in parentheses, R² = coefficient of determination. TBBMC = total body mineral content; LTM = lean tissue mass; TBBMC/LTM, TBBMC by DXA relative to LTM by DXA; DXA = dual-energy X-ray absorptiometry; BMI = body mass index; BIA = bioimpedance analysis. The age-specific equation of Durnin and Womersley (10) was used to predict %BF by skinfold thickness. Deurenberg's sex-specific equation (11) was used for prediction of %BF by BIA. Deurenberg's age-specific equations were used for prediction of %BF by BIA (13, 14).


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