Application of Bioelectrical Impedance Analysis to Elderly Populations

Ronenn Roubenoff,1 Richard N. Baumgartner,2 Tamara B. Harris,1 Gerard E. Dallal,1 Marian T. Hannan,4 Christina D. Economos,1 Patricia M. Stauber,2 Peter W.F. Wilson,1 and Douglas P. Kiel6

1Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston.
2Clinical Nutrition Program, University of New Mexico School of Medicine, Albuquerque.
3Geriatric Epidemiology Office, National Institute on Aging, Bethesda, Maryland.
4Boston University School of Medicine.
5Framingham Heart Study, Framingham, Massachusetts.
6Hebrew Rehabilitation Center for Aged Research and Training Institute, Boston.

Background. Bioelectrical impedance analysis (BIA) can potentially be used to estimate body composition in large populations studied at multiple sites. However, it is not clear whether age-specific BIA equations are necessary for accurate application of BIA to research on elderly subjects.

Methods. We compared a published equation designed to predict fat-free mass (FFM) that had been derived in a young healthy population (mean age 27 y; mean BMI 23.9 kg/m2), with equations that we developed for the elderly by using data from 455 participants in the Framingham Heart Study (78 y; 27.3 kg/m2), using dual-energy x-ray absorptiometry (DXA) as a reference technique. The BIA equations were then compared in an independent sample of 283 participants in the New Mexico Aging Process Study (76 y, 25.5 kg/m2), who also underwent BIA and DXA.

Results. When the young-population equation was applied to Framingham, it caused an overestimation of FFM in heavier subjects that was eliminated by use of the age-specific equation. However, when the two equations were tested in the New Mexico population, the published equation gave estimates of FFM that were closer to DXA than the Framingham equations did.

Conclusions. The accuracy of a BIA equation depends on the body composition of the population and the validation method rather than on age per se. Application of BIA to elderly populations requires uniform validation procedures in the actual study population, rather than reliance on age-specific equations.

As the human body ages, its function and composition change in predictable ways (1). Even if weight remains stable with age, there is a decline in lean body mass and an increase in fat mass in most people (2–6). Decline in lean mass is associated with reduced muscle mass, reduced strength and functional capacity, and eventually death (7–11). As the proportion of the population over age 65 increases (12), measurement of body composition in aging populations is of great interest for both scientific and policy reasons. Unfortunately, the usual reference body composition methods — whole body counting of potassium, hydrodensitometry, dual-energy x-ray absorptiometry (DXA), and isotope dilution — are expensive and often impractical in large population studies. Those methods that are particularly feasible in the field — body mass indices, anthropometry, and bioelectrical impedance analysis (BIA) — also have limitations. For instance, we (13, 14) and others (15) have shown that the body mass index (BMI, kg/m2), developed to standardize weight for height, poorly reflects body composition, particularly body fat, in old age. Interobserver variability is a major limitation of anthropometry, which has a standard error of the estimate (SEE) of 2.2–4.9 kg fat-free mass (FFM) even in well-controlled laboratory settings [reviewed in (16)].

On the other hand, BIA is intrinsically (electronically) precise, with a coefficient of variation of 1–2%, and requires limited operator training. The problem with BIA appears to be in the interpretation of the raw data (resistance and reactance) as measures of body composition. At a recent NIH Technology Assessment Conference (17), discussion focused on the empiric nature of BIA, reflecting both problems in the inherent assumptions of the method and problems in the models required to translate raw BIA data into body composition. The inherent assumptions of BIA are: (a) that the body is cylindrically shaped in terms of electrical conductivity, and (b) that the relationship between body composition and electrical impedance is uniform within and between individuals. BIA data further require a regression equation that reliably translates the resistance and reactance into liters of total body water (TBW) and kg of FFM. This equation is developed by measuring body composition in a defined population using BIA and a reference method such as hydrodensitometry, isotope dilution, or DXA. Unfortunately, hydrodensitometry is unfeasible for many subjects,
especially those who are elderly or debilitated. Furthermore, we (18) and others (19) have recently demonstrated that there are large differences in soft tissue estimates obtained from different DXA machines.

Based on changes in body composition and changes in health status known to be common in old age (6,20), it has been suggested that application of BIA to an elderly population may require that BIA equations be developed using an elderly reference population (21). To examine the precision of BIA in an elderly ambulatory population, we developed BIA equations using DXA in the Framingham Heart Study. The ability of the BIA equations to predict DXA-derived FFM was tested under ideal conditions by applying the BIA equation back to the population in which it was derived. We also compared the performance of the new equations to that of a published BIA equation derived from a healthy younger population (22). Finally, the performance of both equations was tested in an independent sample of elderly subjects from the New Mexico Aging Process Study to examine the behavior of the new equation in a similarly aged, independent sample.

MATERIALS AND METHODS

Study populations. — Body composition was measured in conjunction with the 22nd biennial examination cycle (1992–1993) of the Framingham Heart Study (FHS). Of the original 5,209 FHS participants, approximately 862 survivors attended this examination cycle, with an average age of 78 years (maximum age, 92). This study includes only ambulatory Framingham study subjects, 99% of whom are White. The data presented here are those obtained for the first 466 participants of this cycle. Eleven subjects were excluded because of incorrect electrode use, leaving 455 subjects who had both BIA and DXA measurements. The current sample is representative of the cohort and is identical in gender proportion, age structure, and race to the remainder of the cohort.

The bioimpedance equations were validated in the New Mexico Aging Process Study (NMAPS), a longitudinal study of nutrition and aging begun in 1979. Ninety-six percent of the participants are non-Hispanic Caucasians, and 4% are Hispanic. These elderly volunteers are generally somewhat above average in income, education, and health, and the study population does not represent a population-based sample. Measurements of body composition have been made since 1991, and the data in the present study were collected in 1994 for 284 (86%) of the active, ambulatory study participants that year. A more complete description of the NMAPS cohort has been published (23).

Body composition measurements. — In FHS, height was measured to the nearest .25 inches using a stadiometer. Weight was measured with subjects wearing robes and without shoes, using a standing beam balance, to the nearest .25 pound, in keeping with practices of previous examination cycles. English measures were converted to metric by computer program after data entry. BIA was carried out using standard tetrapolar technique according to the manufacturer’s instructions (BIA-101, RJL Systems, Detroit). Electrodes were placed in standard distal positions on the dorsum of the foot and hand. All subjects were measured in the supine position between 1 and 3 p.m., and had last eaten at least 4 hours previously. Subjects lay supine for < 10 minutes before BIA measurements, as an electrocardiogram was performed prior to BIA. The BIA instrument was calibrated weekly using a 500 ohm high-precision resistor as recommended by the manufacturer. DXA was performed within 2 weeks of the BIA, using a Lunar DPX-L whole body scanner in fast mode at 150 mA. The manufacturer’s acquisition and analysis software (Version 1.3) was used to produce measures of bone, fat-free mineral-free mass, and fat mass.

In the NMAPS study, weight was measured to the nearest 0.1 kg using a beam balance scale, and stature to the nearest 0.1 cm using a wall-mounted stadiometer. BIA was measured using standard tetrapolar technique with a BCA analyzer (BCA, Inc., Schaumberg, IL) after the subjects lay supine for about 15 minutes. This analyzer operates at 50 kHz and 800 μA and provides resistance measurements that are essentially identical, within the precision of the instruments, to those obtained with the RJL BIA 101 analyzer. To confirm this, BIA was measured using both the RUL and BCA analyzers in a subset of 27 subjects in the NMAPS. The mean difference between BCA and RUL measurements was 1.96 Ω (34%) for resistance, and 44 Ω (80%) for reactance. The correlations between BCA and RUL measures were r = .99 for resistance and r = .94 for reactance. The calibration of both analyzers was checked daily against a 500 Ω high-precision resistor. Measurements of bone, lean soft tissue, and fat masses were obtained using a Lunar DPX absorptiometer using version 3.6z of the manufacturer’s software. This version is functionally identical to version 1.3 for the DPX-L. The medium scan speed (20 min) was used for most subjects, with the exception of a few men with trunk thicknesses greater than 27 cm, for whom the slow (40-min) scan speed was used.

Data analysis. — FFM_{obs} was calculated as the sum of BMC plus fat-free, mineral-free mass. Equations for predicting FFM from BIA (FFM_{BIA}) were developed in the study population using multiple linear regression (24) of FFM_{DXA} on height (cm)/resistance, reactance, and weight (kg), separately for men and for women. These covariates were chosen because they are the most frequently used variables in the literature, and because they are easily obtained in field settings without the need for more cumbersome anthropometric measurements. Men and women were analyzed both separately and together. The standard deviation, the standard error of the estimate (SEE, equal to the standard deviation of the mean difference between methods), the difference between means, and the correlation (r) between FFM_{BIA} and FFM_{DXA} were calculated.

The PRESS statistic (25) was calculated to examine the validity of BIA in the FHS population. In the PRESS procedure, each data point is predicted from the least squares fitted regression function developed using the remaining data points, and the sum of the squared differences between observed and predicted values is accumulated (25). While the PRESS statistic must always be larger than the sum of

Material and Methods

Study populations. — Body composition was measured in conjunction with the 22nd biennial examination cycle (1992–1993) of the Framingham Heart Study (FHS). Of the original 5,209 FHS participants, approximately 862 survived this examination cycle, with an average age of 78 years (maximum age, 92). This study includes only ambulatory Framingham study subjects, 99% of whom are White. The data presented here are those obtained for the first 466 participants of this cycle. Eleven subjects were excluded because of incorrect electrode use, leaving 455 subjects who had both BIA and DXA measurements. The current sample is representative of the cohort and is identical in gender proportion, age structure, and race to the remainder of the cohort.

The bioimpedance equations were validated in the New Mexico Aging Process Study (NMAPS), a longitudinal study of nutrition and aging begun in 1979. Ninety-six percent of the participants are non-Hispanic Caucasians, and 4% are Hispanic. These elderly volunteers are generally somewhat above average in income, education, and health, and the study population does not represent a population-based sample. Measurements of body composition have been made since 1991, and the data in the present study were collected in 1994 for 284 (86%) of the active, ambulatory study participants that year. A more complete description of the NMAPS cohort has been published (23).

Body composition measurements. — In FHS, height was measured to the nearest .25 inches using a stadiometer. Weight was measured with subjects wearing robes and without shoes, using a standing beam balance, to the nearest .25 pound, in keeping with practices of previous examination cycles. English measures were converted to metric by computer program after data entry. BIA was carried out using standard tetrapolar technique according to the manufacturer’s instructions (BIA-101, RJL Systems, Detroit). Electrodes were placed in standard distal positions on the dorsum of the foot and hand. All subjects were measured in the supine position between 1 and 3 p.m., and had last eaten at least 4 hours previously. Subjects lay supine for < 10 minutes before BIA measurements, as an electrocardiogram was performed prior to BIA. The BIA instrument was calibrated weekly using a 500 ohm high-precision resistor as recommended by the manufacturer. DXA was performed within 2 weeks of the BIA, using a Lunar DPX-L whole body scanner in fast mode at 150 mA. The manufacturer’s acquisition and analysis software (Version 1.3) was used to produce measures of bone, fat-free mineral-free mass, and fat mass.

In the NMAPS study, weight was measured to the nearest 0.1 kg using a beam balance scale, and stature to the nearest 0.1 cm using a wall-mounted stadiometer. BIA was measured using standard tetrapolar technique with a BCA analyzer (BCA, Inc., Schaumberg, IL) after the subjects lay supine for about 15 minutes. This analyzer operates at 50 kHz and 800 μA and provides resistance measurements that are essentially identical, within the precision of the instruments, to those obtained with the RJL BIA 101 analyzer. To confirm this, BIA was measured using both the RUL and BCA analyzers in a subset of 27 subjects in the NMAPS. The mean difference between BCA and RUL measurements was 1.96 Ω (34%) for resistance, and 44 Ω (80%) for reactance. The correlations between BCA and RUL measures were r = .99 for resistance and r = .94 for reactance. The calibration of both analyzers was checked daily against a 500 Ω high-precision resistor. Measurements of bone, lean soft tissue, and fat masses were obtained using a Lunar DPX absorptiometer using version 3.6z of the manufacturer’s software. This version is functionally identical to version 1.3 for the DPX-L. The medium scan speed (20 min) was used for most subjects, with the exception of a few men with trunk thicknesses greater than 27 cm, for whom the slow (40-min) scan speed was used.

Data analysis. — FFM_{obs} was calculated as the sum of BMC plus fat-free, mineral-free mass. Equations for predicting FFM from BIA (FFM_{BIA}) were developed in the study population using multiple linear regression (24) of FFM_{DXA} on height (cm)/resistance, reactance, and weight (kg), separately for men and for women. These covariates were chosen because they are the most frequently used variables in the literature, and because they are easily obtained in field settings without the need for more cumbersome anthropometric measurements. Men and women were analyzed both separately and together. The standard deviation, the standard error of the estimate (SEE, equal to the standard deviation of the mean difference between methods), the difference between means, and the correlation (r) between FFM_{BIA} and FFM_{DXA} were calculated.

The PRESS statistic (25) was calculated to examine the validity of BIA in the FHS population. In the PRESS procedure, each data point is predicted from the least squares fitted regression function developed using the remaining data points, and the sum of the squared differences between observed and predicted values is accumulated (25). While the PRESS statistic must always be larger than the sum of
squares error found with the entire data set (because the regression fit with a case removed can not be as good as one with the case included), close agreement between PRESS and the observed sum of squares suggests that the \( SEE \) obtained in the FHS population is a valid estimate of the new BIA equation’s predictive capability (25).

\[
\text{FFM}_{\text{BIA}} \text{ was also compared to BIA calculated using a published equations (FFM}_{\text{BIA}} \text{) using height, resistance, reactance, weight, and sex (22,26):}
\]

\[
\text{FFM (kg) = -4.03 + .734 \times (Ht/R) + .116 \times (weight) + .096 \times (Xc) + .984 \times (Sex)} \quad (1)
\]

where \( Ht \) is height in cm, \( Xc \) is reactance in \( \Omega \), and sex = 0 for women and 1 for men. The characteristics of the population in which this equation was derived are shown in Table 1. The validation method for the published equation was hydrodensitometry (26).

Finally, a comparison of the published and new equations was undertaken in the NMAPS population. Mean difference, standard deviation, correlation, and \( SEE \) were calculated as described above. Residual plots of the difference between \( \text{FFM}_{\text{BIA}} \) and \( \text{FFM}_{\text{DXA}} \) against the mean of these values were used to examine bias across the distribution of FFM.

### RESULTS

**Study population.** — Table 1 shows the characteristics of the study populations. The two elderly populations had a similar age distribution, with a mean age of the FHS participants of 78 y and in the NMAPS participants of 76 y. These two populations were also similar in mean weight. However, the FHS and NMAPS populations differed significantly \((p < .01)\) in height, BMI, \( \text{FFM}_{\text{DXA}} \), and percent body fat (determined by DXA). In both cohorts, weight calculated from height, BMI, \( \text{FFM}_{\text{DXA}} \), and percent body fat (determined by DXA) was undertaken in the NMAPS population. Mean difference, standard deviation, correlation, and \( SEE \) were calculated as shown in Table 1. The validation method for the published equation was hydrodensitometry (26).

The differences in predicted values from Equations (4) and (5) had a mean difference of 0 kg and a standard deviation of .33 kg, with a maximum absolute difference of 1.29 kg. Age was not a significant covariate in any of these equations after inclusion of the other terms.

### Precision and Accuracy of BIA equations in FHS. — The new equations correlated well with \( \text{FFM}_{\text{DXA}} \), as expected (Figure 1). The mean difference in \( \text{FFM} \) between \( \text{FFM}_{\text{BIA}} \) and \( \text{FFM}_{\text{DXA}} \) was 0.00, as expected when the equation is applied

### Table 1. Characteristics of Study Populations

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>FHS ((n = 161))</th>
<th>NMAPS ((n = 116))</th>
<th>Published ((n = 47))</th>
<th>FHS ((n = 294))</th>
<th>NMAPS ((n = 167))</th>
<th>Published ((n = 67))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>78.2 (4.3)a</td>
<td>76.2 (5.6)a</td>
<td>26.9 (8.0)</td>
<td>78.4 (4.5)a</td>
<td>75.8 (6.6)a</td>
<td>27.0 (6.4)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>78.4 (12.1)a</td>
<td>76.8 (11.0)a</td>
<td>86.0 (16.4)</td>
<td>63.8 (11.9)a</td>
<td>63.4 (11.2)a</td>
<td>61.8 (10.4)a</td>
</tr>
<tr>
<td>Height, cm</td>
<td>167.3 (7.3)</td>
<td>173.0 (6.5)</td>
<td>182.4 (9.1)</td>
<td>153.4 (6.6)</td>
<td>158.7 (6.0)</td>
<td>166.3 (8.3)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>28.0 (3.7)</td>
<td>25.7 (3.4)b</td>
<td>26.0 (4.9)</td>
<td>27.1 (4.7)</td>
<td>25.3 (4.0)</td>
<td>22.4 (3.6)</td>
</tr>
<tr>
<td>Resistance, ( \Omega )</td>
<td>461.8 (59.2)a</td>
<td>496.2 (54.6)a</td>
<td>432.4 (59.2)</td>
<td>555.9 (70.0)</td>
<td>613.0 (60.5)</td>
<td>559.7 (51.3)</td>
</tr>
<tr>
<td>Reactance, ( R )</td>
<td>48.4 (15.4)a</td>
<td>47.4 (7.3)a</td>
<td>60.4 (7.4)</td>
<td>50.3 (12.4)</td>
<td>54.1 (7.8)</td>
<td>64.9 (8.9)</td>
</tr>
<tr>
<td>( \text{FFM}_{\text{sum}} )</td>
<td>53.9 (6.7)a</td>
<td>55.7 (6.0)a</td>
<td>71.5 (12.0)</td>
<td>37.2 (4.4)</td>
<td>39.0 (6.0)b</td>
<td>46.0 (6.7)b</td>
</tr>
<tr>
<td>% fat*</td>
<td>30.7 (7.0)</td>
<td>26.8 (7.0)</td>
<td>16.2 (7.0)</td>
<td>40.6 (7.6)</td>
<td>37.4 (6.0)</td>
<td>25.1 (6.6)</td>
</tr>
</tbody>
</table>

**Notes:** Data shown are mean (SD). Letters that are the same indicate that the 99% confidence intervals around the sex-specific group means overlap. FHS = Framingham Heart Study; NMAPS = New Mexico Aging Process Study.

* Determined by reference methods of DXA in the two elderly populations and hydrodensitometry in the published equation population.
Figure 1. Comparison of FFM\textsubscript{bio} with FFM\textsubscript{DXA} in the FHS population. Left: Distribution of FFM\textsubscript{bio} vs FFM\textsubscript{DXA} based on the new equation (A) and published equation (B). The solid line is the line of identity. Right: Distribution of the difference between FFM\textsubscript{bio} and FFM\textsubscript{DXA} (residual) and the estimated FFM\textsubscript{bio} for the new equation (C) and the published equation (D). The solid line is the regression line. All data are in kg.

Application of BIA equations in NMAPS. — The predictive accuracy of the sex-specific FHS BIA equations was then tested in an independent elderly population using the NMAPS cohort. In NMAPS, FFM\textsubscript{bio} predicted using the...
FHS equation was compared to FFM_{DXA} obtained in New Mexico using a Lunar DPX densitometer (Table 2). The mean (± SD) difference between FFM_{BIA} and FFM_{DXA} was 2.50 ± 2.9 kg in the men and 2.50 ± 1.88 kg in the women. This mean difference was significantly different from zero (p < .0001). The SEE of FFM_{BIA} in the NMAPS population was 2.34 kg for the men and 1.58 kg for the women, somewhat lower than the SEEs seen with this equation in FHS. The correlation between FFM_{BIA} and FFM_{DXA} was .87 in the men (R² = .77, p < .0001) and .86 in the women (R² = .74, p < .0001), essentially identical to those seen in FHS. However, the FHS equation led to a systematic overestimation of FFM when applied to NMAPS that had a curvilinear distribution (Figure 2). As was seen with the published equation in FHS, the new equation’s error could not be corrected by simply subtracting an “offset” factor.

However, to our surprise, when the published equation was applied to the NMAPS population, it behaved extremely well. The mean difference between FFM_{BIA} derived from the published equation and FFM_{DXA} was not significantly different from zero (Table 2). The correlation coefficients and SEEs were comparable to those seen with the FHS equation in NMAPS. Most importantly, there was no evidence of a systematically increasing overestimation with increasing FFM when the published equation was applied to NMAPS, as there had been in the FHS population (Figure 2).

**Discussion**

In this study — to our knowledge the largest to date examining BIA in the elderly — we developed specific BIA equations for men and women over age 70 using DXA as the reference method. These equations, accurate and precise in their own population, eliminated a systematic overestimation of FFM that occurred when a published equation was applied to this elderly population. However, when the new equations were applied to another population of equally old subjects with somewhat different body composition, they caused a systematic overestimation of lean mass that was not seen with the published equations. It should be noted that in both elderly populations, there is a BIA equation that provides precise and accurate measurements of FFM, supporting the contention that BIA is an acceptable method of estimating body composition in large populations of elderly subjects. However, the issue of which equation to use is not a simple one: use of a BIA equation in the “wrong” population can lead to substantial errors (see Figures 1 and 2).

In all four situations, the mean differences, correlation coefficients, and SEEs were similar: it is only with graphical examination of the data over the range of FFM that the errors became apparent. We conclude that BIA equations are subject to errors that cannot be determined a priori unless they are validated in the specific population in which they are to be applied. This phenomenon does not seem to be age-specific, as we found equally large errors when an equation derived in an elderly population was applied to another elderly population as we did when an equation derived in a young population was applied to that elderly population. The published equation, derived in the thinner and younger population, underestimated FFM in the Framingham cohort, who are older and heavier (the residuals are negative in Figure 1, bottom right). Similarly, the new equation, derived in the FHS population, overestimated FFM when applied to the taller and less obese NMAPS population despite the similarity in their ages (the residuals are positive in Figure 2, top right). Therefore, it appears that the behavior of any BIA equation outside its own population is potentially problematic, and must be validated in a statistical sample of that population before its results can be accepted as accurate.

In addition to the effect of different populations’ body compositions on the behavior of BIA equations, it is important to consider the effect of the validation instruments used to generate the equations and to measure FFM_{DXA}. We used two slightly different models of Lunar densitometers at the

<table>
<thead>
<tr>
<th>Study Population and Equation</th>
<th>Mean Difference (FFM_{BIA} - FFM_{DXA}, kg)</th>
<th>Correlation and Determination (r, R²)</th>
<th>SEE, kg</th>
<th>PRESS statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHS Published</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>-2.13**</td>
<td>0.85, 0.72</td>
<td>4.04</td>
<td>n.a.</td>
</tr>
<tr>
<td>Women</td>
<td>-2.64**</td>
<td>0.88, 0.77</td>
<td>2.69</td>
<td></td>
</tr>
<tr>
<td>New</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>0.00</td>
<td>0.85, 0.72</td>
<td>3.43</td>
<td>1886 2020</td>
</tr>
<tr>
<td>Women</td>
<td>0.00</td>
<td>0.88, 0.77</td>
<td>2.09</td>
<td>1285 1324</td>
</tr>
<tr>
<td>NMAPS Published</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>0.47</td>
<td>0.87, 0.75</td>
<td>3.20</td>
<td>n.a.</td>
</tr>
<tr>
<td>Women</td>
<td>0.12</td>
<td>0.85, 0.73</td>
<td>2.23</td>
<td>n.a.</td>
</tr>
<tr>
<td>New</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>2.50**</td>
<td>0.87, 0.77</td>
<td>2.34</td>
<td>n.a.</td>
</tr>
<tr>
<td>Women</td>
<td>2.50**</td>
<td>0.86, 0.74</td>
<td>1.58</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

Notes: RSS = residual sum of squares; PRESS = predicted residual sum of squares. **p < .01 vs 0.
Figure 2. Comparison of FFM_{DXA} with FFM_{bma} in the NMAPS population. Left: Distribution of FFM_{DXA} vs FFM_{bma} based on the new equation (A) and published equation (B). The solid line is the line of identity. Right: Distribution of the difference between FFM_{DXA} and FFM_{bma} (residual) and the estimated FFM_{bma} for the new equation (C) and the published equation (D). The solid line is the regression line. All data are in kg.

two study sites (DPX-L in Framingham, DPX in Albuquerque), with analogous versions of the software according to the manufacturer's instructions. Although DXA appears to provide a precise and accurate measure of soft tissue mass, with a correlation between FFM_{DXA} and FFM from hydrodensitometry of .92 (27), recent data suggest that individual DXA instruments can lead to important errors, even when instruments from the same manufacturer are used. Comparison of the measurements of fat-free, mineral-free mass between DPX and DPX-L was carried out by Economos et al. (18), using 5 healthy human subjects who were scanned by each model using the software versions used in this study. There was a small but statistically significant difference in fat-free mineral-free mass between DPX and DPX-L of 1.94 kg ($p < .05$), with the DPX-L giving the lower mean reading. However, after adjustment for changes in body weight during the interval between measurements, the difference between the instruments was no longer significant. The difference in fat-free mineral-free mass between DPX and DPX-L using the phantom was 1.3 kg (nonsignificant).

Recently, results similar to those of Economos et al. were reported by Paton et al. (19), using two densitometers of the same model (Lunar DPX). Although extremely precise in measuring bone mass (within 31 g), the two instruments...
differed by up to 6 kg of lean mass when six weight-stable subjects were measured using each machine. We can not eliminate the possibility that the differences in body composition seen between New Mexico and Framingham were due to the use of separate DXA scanners. However, this would not explain the observation that the published equation performed well in NMAPS but not in FHS, since the published equation relied on hydrodensitometry rather than DXA for validation. It is possible, however, that the difference between the hydrodensitometry and the NMAPS DXA was systematically less than between hydrodensitometry and the FHS DXA, contributing to better accuracy of the published equations in New Mexico compared to Framingham. Nevertheless, our observations illustrate that multicenter studies cannot rely on separate DXA instruments for validation. As a standardized soft-tissue phantom is not currently available, this suggests that transporting human subjects between test sites periodically during the study is necessary, with its attendant costs and inconveniences. In addition, repeat standardization following software upgrades or instrument modifications may also be necessary.

We have previously pointed out the potential pitfalls of DXA measurement in very young and very sick populations, where hydration of lean mass is often abnormal (28). The potential effect of hydration of lean mass is more likely to impact hydrodensitometry than DXA, and recent calculations by Heymsfield et al. suggest, in fact, that the sensitivity of DXA to hydration is very low (29). Most importantly, underwater immersion is frightening and impractical for some elderly subjects, limiting its usefulness in frail or ill populations. Finally, comparing the new BIA equation to FFMDXA in both FHS and NMAPS removes this problem insofar as the validation study is concerned.

The use of different BIA analyzers in the two studies is unlikely to have produced an important bias, because the resistance and reactance measurements are essentially identical between these devices (see Methods). Error due to technical factors was minimized in this study by studying all patients using the same electrode placement, time of day, postprandial state, and duration of supine position prior to measurement of BIA. Furthermore, because our population included only ambulatory, relatively healthy subjects, extremes of overhydration or dehydration were avoided. However, mild dehydration or overhydration in the elderly is common and could certainly have occurred in our population. Since we were interested in the behavior of BIA under field conditions, no attempt was made to exclude subjects on the basis of hydration status. For the same reason, we only chose the most commonly used and easily measured covariates — height, weight, sex, resistance, and reactance — and did not include limb circumferences or other anthropometric data.

Because of its low cost and ease and rapidity of use, the greatest potential utility of BIA is in studies of large populations. To date, the only measures used to grade body composition in very large studies such as the Build Study (30) have been relative weight, weight for height, or BMI. Compared to the BMI, which has a coefficient of determination (R²) of roughly .38 to .55 as a measure of fatness in the FHS cohort (14), BIA represents an important improvement in the epidemiologic methods of body composition (13–15,31,32).

However, our data suggest that any population-based study of body composition in which BIA is used should include validation of the chosen BIA equation in a subset of the population in order to ascertain the appropriateness of the selected equation.

Acknowledgments

This study was supported by NIA-USDA Interagency Agreement Y01 AG-20195 and National Institutes of Health Grants DK-08443 to R. Roubenoff, AR-41398 to D. P. Kiel, and AG-08510 to R. N. Baumgartner. The contents of this publication do not necessarily reflect the views or policies of the U.S. Department of Agriculture nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

The authors thank Norma Davis, Sharron Rich, Sue Anderson, Cherlyn Mercier, and other staff members of the Framingham Heart Study for their painstaking data collection. Dr. Joseph J. Kehayas for his helpful comments, and Trudy Hedrick for data entry.

Address correspondence to Dr. Ronenn Roubenoff, Body Composition Laboratory, USDA HNRCA at Tufts University, 711 Washington Street, Boston, MA 02111. E-mail: roubenoff@hnrc.tufts.edu

References


Received March 12, 1996
Accepted September 11, 1996

AGE STUDIES AWARD

The Gerontological Society of America and The University Press of Virginia announce a new award to be given biannually to an outstanding book-length manuscript in interdisciplinary scholarship on aging written for a humanities audience. The winner will receive $1,000 and publication in the University Press of Virginia’s Age Studies Series.

Deadline for submissions for the first award is October 31, 1997.

Submission Requirements: Applicants are asked to send three copies of a description with table of contents, a sample chapter, and the author’s CV to

Age Studies Award
University Press of Virginia
Box 3608 – University Station
Charlottesville, VA 22903

Finalists will subsequently be asked to send five copies of the complete manuscript. Announcement of the winner will be made on or about June 15, 1998.

Review Criteria: Submissions will be judged by the Humanities and Arts Committee of The Gerontological Society of America on the basis of creativity, originality, contribution to the field, and appropriateness for publication in the Age Studies series. Applicants are encouraged to look at the volume Aging and Gender in Literature: Studies in Creativity, edited by Anne M. Wyatt-Brown and Janice Rossen (Virginia. 1993), to form an idea of the range of work of interest to the series.

Only original unpublished submissions not presently under consideration by a publisher will be considered. Manuscripts will not be returned.