Measuring the body composition of elderly subjects: a comparison of methods

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There is a paucity of data on differences between methods for the assessment of body composition in elderly subjects. Studies on younger adults suggest that such differences are of some practical significance at the individual level. In the present study the following methods of estimating percentage body fatness (BF%) were compared in healthy elderly men and women (mean age 70 (SD 6) years: densitometry; skinfold thickness; total body water; bioelectrical impedance (BIA) using an age-specific predictive equation and the manufacturers' equation; body mass index (BMI). Though BF% estimates from the various methods tended to be highly correlated with those from densitometry and with each other, differences between methods at the individual level were marked. In particular, the age-specific equations based on BMI and BIA systematically overestimated BF% relative to the other methods. Biases between BF% estimates derived from densitometry, skinfolds, BIA (manufacturers' equation) and total body water were less marked, indicating little evidence of systematic differences between these methods in elderly subjects. Individual differences between methods were slightly greater than those reported in some studies of younger adults, but this may be of little practical significance, and may be considered inevitable in view of variability between and within subjects in the extent to which the underlying assumptions of these two-component methods are met in elderly subjects.

Fat-free mass: Ageing: Methodology

The need for improved information on the methodology for assessment of body composition of elderly subjects (> 65 years) has been identified by a number of investigators (e.g. Durnin, 1983; Kuczmarski, 1989; Baumgartner *et al.* 1991). Ageing is characterized by: reduction in fat-free mass (FFM; Forbes, 1987), primarily via loss of muscle mass; loss of bone mineral in women (Mazess, 1982); redistribution of body fat leading to increased deposition of body fat in 'internal' fat depots as opposed to subcutaneous depots (Durnin & Womersley, 1974). Though the general pattern of change in body composition in old age is clear, it is also clear that the rate, timing and extent of the changes varies between subjects and between the sexes (Deurenberg *et al.* 1989; Heymsfield *et al.* 1989). Both the changes and the degree of variability in the changes present particular problems for the assessment of body composition by two-component methods in elderly subjects since the underlying assumptions upon which the various techniques are based may be invalid. Concern has been expressed in relation to the use of total body K which is flawed by loss of muscle in old age (Cohn *et al.* 1980). Estimates using total body water (TBW) may also be flawed if the water content of FFM alters systematically with old age, but there is little evidence of a systematic change of this kind (Schoeller, 1989). Bioelectrical impedance (BIA) has practical utility in elderly subjects but use of age-specific predictive equations is likely to be necessary, since application of equations derived from younger populations in elderly subjects may lead to systematic overestimation of FFM (Deurenberg *et al.* 1990). The prediction of body density by skinfold thickness is of value in elderly subjects, but concern has been expressed in relation to overestimation of body density particularly in women (Reilly *et al.* 1993). An alternative anthropometric approach based on prediction of body fatness in individuals from body mass index (BMI) has been shown to have some promise (Deurenberg *et al.* 1991) in elderly subjects. Finally, in most studies which have adopted two-component methods the reference method adopted is body density, but there are particular problems with the use of densitometry as a reference method in the elderly because of variability in the density of FFM such that the assumption of a constant density of 1·100 kg/m^3 may be invalid (Deurenberg *et al.* 1989).

In recent years advances in technology have permitted the construction of models of body composition which define the body in terms of more than two components. These models are of particular value in population groups where the two-component model is limited by variability in the composition of FFM, notably in children and the elderly (e.g. Svendsen *et al.* 1991; Friedl *et al.* 1992). However, further development of this approach is necessary and cross-validation of any equations arising from it is awaited. For many investigators two-component methodology will remains the only option for the foreseeable future because of practical constraints. Moreover, in many 'field', community, and clinical settings the techniques derived from the two-component approach (e.g. skinfold thickness and BIA) are the only appropriate means of body composition assessment. Our approach here has been to characterize differences between two-component methods currently available for use in elderly subjects. Detailed characterization of differences between methods at the level of the individual is virtually absent in elderly subjects. These differences are quite marked in younger groups of adults (McNeill *et al.* 1991; Fuller *et al.* 1992) and might be even more marked in elderly subjects because of variability in the rate, extent or timing of the changes in body composition outlined above.

The aims of the present study were as follows: (1) To compare methods for the assessment of body composition in healthy elderly subjects by application of several methods on the same subject; (2) to test the validity of predictive equations based on BIA and BMI, developed in other elderly populations, for use in the selected population recruited in this study.

SUBJECTS AND METHODS

Subjects

The participants were sixty elderly subjects (thirty-three females, twenty-seven males). All were in good health, living in the community, and were recruited by newspaper advertisement. All subjects provided a brief medical history and were free of disease which might have been relevant to consideration of body composition (diagnosis of osteoporosis, renal or hepatic disease, malignancy, cardiovascular disease). The research was approved by the Glasgow West Ethics Committee, and all subjects provided informed consent to the procedures described here. Characteristics of subjects are given in Tables 1 and 2. Subjects were not selected on the basis that they were to comprise a representative sample of the elderly living in the community, but comparison of the males and females separately with appropriate reference values for the UK (Burr & Phillips, 1984) revealed no significant differences between the sample selected and reference data for community elderly subjects with respect to age, body weight, or body composition estimated from skinfold thickness (t test, $P > 0.05$).

Of the sixty subjects selected, twenty-five were unable or unwilling to participate in the underwater weighing procedure for determination of body density. Subjects in whom density was not measured did not have TBW determined. The remaining thirty-five subjects

Table 1. *Characteristics of male subjects* (n *27*) *participating in the study*

Subject no.	Age (years)	Weight (kg)	Height (m)	BMI (kg/m²)	Participation in complete study*
02	66	87·0	1·82	26·4	Y
03	71	85·0	1·79	26·5	Y
04	67	67·0	1·65	24·7	Y
06	75	83·0	1·67	29·6	N
08	67	88·5	1·75	28·9	Y
09	64	90·0	1·66	32·5	Y
20	72	54·5	1·61	21·0	Y
22	73	59·5	1·65	23·1	Y
33	66	71·1	1·70	24·6	Y
35	65	85·0	1·76	27·4	N
37	65	70·0	1·81	21·3	Y
38	68	79·5	1·85	23·2	Y
39	70	86·5	1·78	27·3	Y
43	66	64·0	1·63	24·2	Y
46	69	79·0	1·78	24·9	Y
50	66	95·8	1·73	31·9	N
51	75	67·0	1·78	21·3	Y
53	71	61·0	1·65	22·5	Y
55	84	60·8	1·59	24·0	N
67	70	93·5	1·85	27·5	Y
69	93	51·2	1·61	19·8	N
70	66	64·5	1·63	24·3	Y
75	65	71·0	1·75	23·1	Y
79	65	93·8	1·79	29·2	Y
87	68	74·8	1·68	26·6	Y
88	71	77·5	1·71	26·5	N
89	66	80·0	1·82	24·2	N
Mean	70	75·6	1·72	25·4	
SD	6	12·7	0·08	3·2	

BMI, body mass index; Y, yes; N, no.

* Subjects who did not participate in the complete study were, by definition, not included in the measurements of total body water and underwater weighing.

participated in all procedures (including measurement of TBW) described below and therefore the sample size for all methodological comparisons was thirty-five (nineteen males, sixteen females), but for comparison of methods other than densitometry and TBW sample size was sixty.

Anthropometry

Subjects visited the laboratory in the early morning after an overnight fast and were weighed to 0·1 kg in light indoor clothing. This was corrected to nude weight. Height was measured to 2 mm. The procedures described below were then performed on the same day.

Skinfold thickness (SFT)

Skinfolds were measured at four standard sites: biceps, triceps, suprailiac and sub-scapular, as previously described (Durnin & Womersley, 1974). Body density was predicted in all subjects using the appropriate equation from Durnin & Womersley (1974). All measurements were carried out by the same trained observer. The estimate of density

Table 2. *Characteristics of female subjects* (n *33*) *participating in the study*

Subject no.	Age (years)	Weight (kg)	Height (m)	BMI (kg/m^2)	Participation in complete study*
01	69	68·5	1·54	29·0	Y
07	72	70·1	1·65	25·9	Y
12	75	58·5	1·59	23·1	Y
15	66	76·5	1·58	30·8	Y
18	66	59·5	1·56	24·5	Y
19	66	67·5	1·62	25·8	Y
21	67	47·5	1·60	18·7	Y
23	71	99·5	1·66	36·0	N
25	79	71·5	1·62	27·2	N
26	68	52·0	1·47	24·0	Y
27	72	71·0	1·56	29·1	N
31	70	70·0	1·57	25·4	N
32	66	62·5	1·57	25·3	N
40	68	56·5	1·57	23·0	Y
42	78	49·3	1·54	20·7	Y
44	66	63·0	1·64	23·4	Y
45	66	70·0	1·52	30·1	N
47	76	61·2	1·56	25·1	Y
48	77	70·3	1·65	26·1	N
49	79	38·8	1·48	17·8	N
52	70	63·8	1·55	26·7	Y
54	74	50·0	1·52	21·5	N
57	76	53·0	1·57	21·5	Y
58	65	66·9	1·62	25·4	N
68	70	51·0	1·48	23·2	Y
76	75	69·0	1·59	27·5	N
77	74	67·0	1·63	25·2	Y
81	69	70·0	1·51	30·7	N
82	65	68·0	1·66	24·8	N
84	65	52·5	1·51	23·2	N
85	69	66·0	1·52	28·6	N
88	74	70·0	1·67	25·1	N
89	69	58·5	1·51	25·7	N
Mean	70	63·0	1·57	25·5	
SD	4	10·9	0·06	3·6	

BMI, body mass index; Y, yes; N, no.

* Subjects who did not participate in the complete study were, by definition, not included in the measurements of total body water and underwater weighing.

obtained was converted to an estimate of body fatness (BF %; percentage of body weight) using Siri's (1961) equation:

$$\text{BF}\,\% = (4{\cdot}95/\text{density}) - 4{\cdot}50.$$

Fatness from body mass index (*BMI*)

BMI was calculated for all subjects and used in the appropriate predictive equation from Deurenberg *et al.* (1991) in order to estimate BF%.

$$\text{BF}\,\% = (1{\cdot}2 \times \text{BMI}) - (10{\cdot}8 \times \text{sex}) + (0{\cdot}23 \times \text{age}) - 5{\cdot}4,$$

where sex is entered as male 1, female 0.

Bio-electrical impedance (BIA)

Whole-body BIA was measured in all subjects at 800 μA and 50 kHZ using an EZ 1500 Body Composition Analyser (Cranlea and Co., Birmingham, West Midlands). The instrument employed the conventional tetrapolar method with electrodes attached to hand and foot. BF% was estimated from the BIA measurement in two ways: (1) using the manufacturer's equation 'built in' to the instrument software; (2) using the appropriate equation derived from a healthy elderly population described by Deurenberg *et al.* (1990):

$$\text{FFM (kg)} = (0{\cdot}671 \times 10^4 \times \text{H}^2/\text{R}) + (3{\cdot}15 \times \text{S}) + (3{\cdot}9)$$

$$(r^2\ 0{\cdot}88;\ \text{standard error of estimate } 3{\cdot}1\ \text{kg}),$$

where H is height (m), R is resistance (ohms), S is sex (entered as females 0; males 1). FM was calculated as (body weight − FFM), and expressed as a percentage of body weight.

Densitometry

Body density (BD) was measured in thirty-five of the sixty subjects by underwater weighing, as previously described, and residual lung volume was determined by N_2 wash-out as previously described (Durnin & Womersley, 1974).

Measurements of body density in men were converted to BF% estimates using Siri's (1961) equation. In the women, BD was converted to BF% using both the Siri equation and a modification of it suggested by Deurenberg *et al.* (1989). Deurenberg *et al.* (1989) demonstrated that FFM density in elderly women is lower than 1·100 kg/m^3 and proposed the following modification to Siri's equation in order to correct for the error observed:

$$\text{Women age 70 years: BF\%} = (512{\cdot}1/\text{density}) - 469{\cdot}0.$$

This equation makes the assumption that the density of FFM is 1·0919 kg/m^3 rather than 1·100 kg/m^3 (Siri, 1961).

Estimation of BF% from TBW

TBW was estimated as ^{2}H^{2}HO dilution space/1·04 (Schoeller *et al.* 1980). After providing a urine specimen for determination of background ^{2}H enrichment in body water, ^{2}H^{2}HO space was measured from the 5–7 h post dose 'plateau' enrichment in urine following oral administration of a weighed dose of approximately 0·12 g ^{2}H^{2}HO/kg body-weight. Background and 'plateau' ^{2}H enrichments were measured using an Aqua Sira isotope ratio mass spectrometer (Bureau for Stable Isotope Analysis, Brentford, Middlesex). TBW was calculated following correction to measured dilution space of ^{2}H^{2}HO for density of water at 37°. Calculation of BF% from TBW was made by assuming that the water content of FFM is 730 g/kg.

As indicated above, measurements of TBW, and estimates of BF% derived from them, were available only for those subjects for whom body density was measured (*n* 35), since TBW was only determined in those subjects who could undertake the underwater weighing procedure.

Statistical analyses

Differences between the subjects recruited to the present study and appropriate reference data (for age, weight, FM and FFM from SFT) were tested for statistical significance by *t* test. Relationships between BF% estimates produced from each of the methods were examined by correlation. Since correlation is an index of association rather than agreement between methods, methodological differences were analysed on the basis of individual

Table 3. *Estimates of percentage body fat (BF%) in male subjects by six methods**

Subject no.	Densitometry†	BMI‡	BIA§ (manufacturer's equation)	BIA‖ (Deurenberg *et al.* equation)	SFT¶	TBW††
02	20·1	30·7	25·5	36·6	32·2	19·1
03	22·1	31·9	23·1	34·1	30·0	30·2
04	23·2	28·9	25·7	34·6	26·6	27·0
08	31·0	33·9	32·8	42·1	29·6	29·4
09	30·6	37·5	32·6	41·8	32·3	33·6
20	16·3	25·6	17·4	27·0	18·1	18·0
22	21·9	28·3	10·7	28·7	23·2	22·0
33	28·0	28·5	19·0	30·0	27·7	27·0
37	23·7	24·3	24·7	34·4	28·1	27·9
38	23·6	27·3	29·5	39·3	29·6	30·0
39	26·5	32·7	33·0	42·0	22·1	24·2
46	13·8	29·6	18·2	28·7	21·2	18·3
51	15·1	26·6	13·3	22·8	19·3	18·3
53	25·2	27·1	16·7	27·3	29·4	22·8
67	28·1	32·9	34·4	42·5	29·5	32·5
70	27·0	28·1	31·6	39·2	29·1	25·1
75	24·2	26·5	20·6	31·0	23·3	19·2
79	26·9	33·8	37·1	45·5	23·8	19·8
87	26·1	31·4	26·1	37·3	28·1	30·0
06	—	36·6	27·4	37·2	27·4	—
35	—	31·6	32·1	41·0	29·0	—
43	—	28·0	35·2	42·5	26·5	—
50	—	37·3	40·8	47·2	27·0	—
55	—	31·9	28·1	37·1	25·5	—
69	—	34·4	20·6	27·9	20·9	—
88	—	31·3	31·0	40·0	26·0	—
89	—	28·0	28·4	38·1	27·8	—
Mean	23·9	30·5	26·5	36·1	26·4	25·0
SD	4·8	3·6	7·6	6·4	3·8	5·2

BMI, body mass index, BIA, bioelectrical impedance; SFT, skinfold thickness; TBW, total body water.
* For details of subjects and procedures, see Table 1 and pp. 34–38.
† Using the equation of Siri (1961).
‡ Using the equation of Deurenberg *et al.* (1991).
§ Using the manufacturer's 'built-in' equation.
‖ Using the equation of Deurenberg *et al.* (1990).
¶ Following the method of Durnin & Womersley (1974).
††Assuming the water content of the fat-free mass is 730 g/kg.

differences in BF% estimates between the various methods. These were expressed as the mean of the individual differences between methods in BF% units ('bias') and the 'limits of agreement' between methods (bias $\pm t \times$ SD of the differences) following the method of Bland & Altman (1986). The appropriate value of t was taken from statistical tables.

RESULTS

Differences between BF% estimates using different methods: males

Individual BF% estimates for each of the six methods used in males are presented in Table 3. Data are presented for each individual in order to illustrate the degree of variability in BF% estimates for the same individual.

Table 4. *Comparison of various body composition methods in male subjects**†

(Bias‡ for estimates of body fatness§ as a percentage of body weight, with 95% limits of agreement (*t* SD) given in parentheses)

Method	Densitometry	Body mass index	BIA (Manufacturer's equation)	BIA (Deurenberg *et al.* (1990) equation)	Skinfold thickness	Total body water
Densitometry	—	—	—	—	—	—
Body mass index	−5·9 (8·6)	—	—	—	—	—
BIA (Manufacturer's equation)	−1·0 (12·0)	4·9 (12·4)	—	—	—	—
BIA (Deurenberg *et al.* (1990) equation)	−11·1 (9·5)	−5·2 (9·7)	−10·2 (4·5)	—	—	—
Skinfold thickness	−2·6 (8·4)	3·3 (8·9)	−1·6 (14·0)	8·5 (11·7)	—	—
Total body water	−1·1 (8·4)	4·8 (10·1)	−0·1 (14·1)	10·0 (12·0)	1·5 (7·8)	—

BIA, bioelectrical impedance.

* For details of subjects and procedures, see Table 1 and pp. 34–38.

† Comparisons between densitometry and total body water and the other methods are based on nineteen subjects; all other comparisons are based on twenty-seven subjects.

‡ The method at the top of the table minus the alternative method given at the left hand side provides the bias.

§ Values for bias of fat-free mass (as a percentage of body weight) are equal and opposite to those given for percentage fat.

Methods tended to be highly correlated with each other and all of the indirect methods were highly correlated with body density (*n* 19): BMI (*r* 0·55; $P < 0·05$); BIA, manufacturer's equation (*r* 0·67; $p < 0·01$); BIA, Deurenberg *et al.* (1990) equation (*r* 0·72; $P < 0·01$); SFT (*r* 0·62; $P < 0·01$); TBW (*r* 0·69; $P < 0·01$). As indicated above, correlation is an index of association rather than agreement. The degree of agreement between methods was determined by the Bland & Altman (1986) analysis which concentrates on individual differences; these results are presented below.

Comparison between methods and densitometry: males

The results of the Bland & Altman (1986) analysis are given in Table 4. Table 4 confirms that the 95% limits of agreement between all methods were wide. Some distinct biases are apparent. In particular, for the consideration of methods in relation to densitometry (*n* 19) it is clear from Tables 3 and 4 that the BMI method and BIA using the equation of Deurenberg *et al.* (1990) tend to overestimate BF% relative to densitometry (large negative bias when BF% estimate is subtracted from BF% by densitometry; Table 4). Agreement between BIA (manufacturer's equation), SFT, and TBW and densitometry was somewhat better as indicated by the smaller biases, but limits of agreement were wide, particularly for BIA (Table 4).

Comparison between methods: males

Table 4 confirms that the greatest bias exists for comparisons of BF% from BIA using the equation of Deurenberg *et al.* (1990) which consistently overestimated BF% relative to other methods. The next highest estimates were obtained by BMI. Bias between BIA (manufacturer's equation), SFT and TBW was less marked, but again limits of agreement were wide.

Table 5. *Estimates of percentage body fat (BF%) in female subjects by seven methods**

Subject no.	Densitometry† (Siri equation)	Densitometry‡ (Deurenberg *et al.* equation)	BMI§	BIA‖ (Manufacturer's equation)	BIA¶ (Deurenberg *et al.* equation)	SFT††	TBW‡‡
01	43·6	41·6	45·3	47·2	42·5	40·6	42·0
07	45·3	43·6	42·2	38·7	49·6	37·4	42·6
12	44·7	42·6	39·6	41·1	52·3	34·8	46·5
15	36·7	34·5	46·7	45·1	55·3	38·5	38·4
18	42·2	40·0	39·2	40·8	52·1	36·7	41·9
19	37·9	35·5	40·7	34·1	47·0	39·5	37·4
21	24·4	22·0	32·5	22·6	39·2	25·9	26·1
26	52·9	52·0	39·0	44·0	54·0	35·2	43·7
40	39·2	37·0	37·8	34·1	46·9	34·4	37·9
42	26·6	24·4	37·4	23·4	37·9	25·1	27·0
44	35·9	33·6	37·9	36·6	48·4	36·9	35·1
47	23·6	21·0	42·2	41·3	52·2	37·1	39·5
52	50·7	48·8	42·7	48·7	57·1	37·7	53·0
57	31·5	29·2	37·9	34·7	46·7	32·9	32·3
68	42·8	41·1	38·5	40·9	51·6	35·7	41·0
77	45·9	44·1	41·9	47·1	49·5	38·0	39·5
10	—	—	38·5	34·6	46·3	32·5	—
23	—	—	54·1	42·9	54·0	44·6	—
27	—	—	46·1	42·4	53·8	40·0	—
31	—	—	41·8	48·1	57·4	38·2	—
32	—	—	40·1	36·5	48·5	36·6	—
45	—	—	45·9	44·5	54·6	36·3	—
48	—	—	43·3	44·5	54·2	35·1	—
49	—	—	34·1	22·7	36·0	24·1	—
54	—	—	37·4	26·6	39·8	32·3	—
58	—	—	40·0	44·5	54·4	37·9	—
76	—	—	44·9	39·8	50·6	35·8	—
81	—	—	47·3	46·6	56·4	41·8	—
82	—	—	39·3	43·1	53·4	39·9	—
84	—	—	37·4	29·3	42·7	37·7	—
85	—	—	44·5	44·2	55·0	35·0	—
88	—	—	41·7	36·3	53·7	37·1	—
89	—	—	42·0	35·3	46·9	38·7	—
Mean	39·0	36·9	41·2	38·9	49·7	36·1	38·9
SD	8·8	9·2	4·2	7·4	5·8	4·4	6·9

BMI, body mass index; BIA, bioelectrical impedance; SFT, skinfold thickness; TBW, total body water.
* For details of subjects and procedures, see Table 2 and pp. 34–38.
† Using the equation of Siri (1961).
‡ Using the equation of Deurenberg *et al.* (1989).
§ Using the equation of Deurenberg *et al.* (1991).
‖ Using the manufacturer's 'built in' equation.
¶ Using the equation of Deurenberg *et al.* (1990).
†† Following the method of Durnin & Womersley (1974).
‡‡ Assuming the water content of the fat-free mass is 730 g/kg.

Differences between BF% estimates using different methods: females

Individual estimates of BF% for each of the seven methods are presented in Table 5. Data are again presented for each individual in order to illustrate the degree of variability in BF% estimates from the various methods.

As in the males, BF% estimates from the various methods tended to be highly correlated with each other and with BF% by densitometry. For example, correlation coefficients for

Table 6. *Comparison of various body composition methods in female subjects**†

(Bias‡ for estimates of body fatness§ as a percentage of body weight, with 95% limits of agreement (*t* SD) given in parentheses)

Method	Densitometry (Deurenberg *et al.* (1989) equation)	Body mass index	BIA (Manufacturer's equation)	BIA (Deurenberg *et al.* (1990) equation)	Skinfold thickness	Total body water
Densitometry (Deurenberg *et al.* (1989) equation	—	—	—	—	—	—
Body mass index	−3·2 (18·1)	—	—	—	—	—
BIA (manufacturer's equation)	−1·8 (14·0)	2·4 (11·2)	—	—	—	—
BIA (Deurenberg *et al.* (1990) equation)	−12·0 (16·0)	−8·5 (9·4)	−10·8 (7·5)	—	—	—
Skinfold thickness	1·5 (16·4)	5·1 (6·3)	2·8 (10·4)	13·5 (9·0)	—	—
Total body water	−2·0 (11·9)	1·2 (12·1)	−0·1 (8·7)	10·0 (8·7)	−3·5 (10·4)	—

BIA, bioelectrical impedance.

* For details of subjects and procedures, see Table 2 and pp. 34–38.

† Comparison between densitometry and total body water and the other methods are based on sixteen subjects; all other comparisons are based on thirty-three subjects.

‡ The method at the top of the table minus the alternative method given on the left hand side provides the bias.

§ Values for bias of fat-free mass (as a percentage of body weight) are equal and opposite to those given for percentage fat.

BF% from densitometry (Deurenberg *et al.* (1990) equation; *n* 16) and other methods were as follows: BMI (*r* 0·38 ; not significant); BIA, manufacturer's equation (*r* 0·71; $P < 0·01$); BIA, equation of Deurenberg *et al.* (1990) (*r* 0·58; $P < 0·05$); SFT (*r* 0·56; $P < 0·05$); TBW (*r* 0·80; $P < 0·01$).

Comparison of methods with densitometry: females

The results of the Bland & Altman (1986) analysis are given in Table 6. Comparisons with densitometry are provided using the modification to Siri's equation proposed by Deurenberg *et al.* (1989). Table 6 confirms that the 95% limits of agreement between methods are wide. As in the males, some distinct biases were apparent (Tables 5 and 6). Comparison of the various methods with densitometry (*n* 16) showed that the BIA method employing the age-specific equation for elderly people proposed by Deurenberg *et al.* (1989) consistently overestimated body fatness relative to densitometry. The equation based on BMI developed by Deurenberg *et al.* (1991) systematically overestimated BF% relative to densitometry, though not to the same extent as in the males (Table 4). Biases for BIA, SFT, TBW and densitometry were considerably smaller but the limits of agreement were fairly wide (less so for TBW than the other methods).

Comparison between methods: females

The estimates of BF% from the age-specific equation based on BIA of Deurenberg *et al.* (1990) were systematically higher than all other methods (Table 6), with estimates of BF% from BMI next highest (Tables 5 and 6). Biases between the other methods were less clear though BIA tended to produce slightly higher estimates than SFT, and SFT tended to produce slightly lower estimates than TBW (Tables 5 and 6). As in the males, however, limits of agreement between these three methods were wide.

The estimates of BF% from densitometry using the correction of Deurenberg *et al.* (1989) are of course lower than those from Siri's equation (Table 5) because of the reduction in the constant assumed for the density of FFM.

DISCUSSION

The approach taken in the present study was to provide a comparison of two-component methods of body composition assessment. Historically such studies have tended to identify a particular method (usually densitometry) as a reference and then compare other methods against the one so designated. In the absence of cadaver analysis such approaches can at best only provide a test of the relative validity rather than absolute validity of any particular method. Given the likely variability in the composition of the FFM of elderly subjects outlined above, and indeed in younger adults (Fuller *et al.* 1992), not only is absolute validity out of the question, but to consider validity relative to a reference method such as densitometry is to put too much faith in the basic assumptions of the two-component model. We have therefore refrained from making judgements of validity of individual methods by comparison with densitometry as a reference method, though the data presented could be used in such a manner (Tables 4 and 6).

Comparison of BF% estimates between the various methods revealed that BIA using the appropriate age-specific regression equation (Deurenberg *et al.* 1990) and prediction of BF% by BMI (Deurenberg *et al.* 1991) both tended to overestimate body fatness relative to the other methods for males and females (Tables 3 and 4 males; Tables 5 and 6 females). Svendsen *et al.* (1991) also found that the age-specific BIA equation of Deurenberg *et al.* (1990) tended to overestimate fatness in their group of healthy elderly subjects, but we know of no other attempt to cross-validate this particular equation, or to cross-validate the prediction of BF% from BMI. Real differences between populations or samples may exist and this finding tends to support the case for a greater degree of cross-validation of predictive formulas, as suggested by several investigators (e.g. Deurenberg *et al.* 1990; Baumgartner *et al.* 1991). These difficulties are likely to be exacerbated when attempts are made to validate methodology based on healthy elderly subjects in elderly populations who are ill or disabled and this represents a major methodological problem.

Bias between the other methods was not particularly marked (Tables 4 and 6) in males or females, but the degree of disagreement in BF% estimates at the individual level might be considered high. Methodological comparison are often made solely by correlation which tends to mask differences between individuals (Bland & Altman, 1986). Recent studies of younger adults have revealed marked differences between methods at the individual level (McNeill *et al.* 1991; Fuller *et al.* 1992). An alternative view may be that the inter-individual differences outlined in Tables 3–6 are inevitable and need not give rise to undue concern. Siri (1961) considered that individual differences between 'true' and estimated BF% of approximately 3·5 BF% between methods were inevitable (arising from error in the basic assumptions and biological variability). Furthermore, comparison of BIA- (manufacturer's equation), TBW- and SFT- (Tables 3–6) derived estimates of BF% perhaps illustrates a degree of disagreement between methods which is not surprising in the light of Siri's comment and may be of little concern. The absence of great bias between these three methods illustrates the apparently limited potential for large systematic differences between the three 'bedside' methods.

The degree of inter-individual variability in composition of the FFM, discussed above, means that differences between methods in elderly subjects might be expected to be greater than in younger adult groups. The present study provides some support for this hypothesis. Fuller *et al.* (1992) for example reported a bias for comparison of SFT and density of −0·66

(2SD 5·00) BF% and 2·63 (2SD 7·87) BF% for comparison of BIA and density in twenty-eight healthy adults (males and females, age range 18–59 years). McNeill *et al.* (1991) reported slightly wider limits of agreement between SFT-density and BIA-density in a smaller (n 14) sample of younger adult women: comparison of BF% by density-SFT (bias −0·3, 2SD 9·8); comparison of BF% by density-BIA (bias 1·7, 2SD 8·6). In the present study, analogous (bias $\pm t \times$ SD) values for the comparison of SFT and density in men (Table 4) were −2·6 (8·4) BF% in men, 1·5 (16·4) BF% in women. For comparison of BIA and density in men (Table 4) bias was −1·0 (12·0) BF% and −1·8 (14·0) BF% in women (Table 6). In both cases limits of agreement for men and women are somewhat greater than those reported by Fuller *et al.* (1992) but only marginally greater than those reported by McNeill *et al.* (1991).

Methods of body composition assessment which are technically simple and can therefore be used in epidemiological and routine clinical settings (SFT, BMI, BIA, and possibly TBW) are of great importance in consideration of nutritional status of the elderly, and further research on the validity and practical utility of the various methods is indicated. A multicomponent approach is likely to be of great use in body composition assessment of the elderly (Baumgartner *et al.* 1991; Svendsen *et al.* 1991; Virgili *et al.* 1992), but cross-validation in different populations must be demonstrated. It is also likely that, with some modifications, the existing 'bedside' two-component methods will remain and the characterization of differences between these methods is of obvious relevance. We conclude that in healthy elderly subjects large systematic differences between D, BIA (at least using the instrumentation software employed here), TBW and SFT are not present. The choice of which method to use in particular circumstances might therefore make little difference in practical terms, particularly if data are to be considered on a group basis.

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