

Calibration and validation of an air-displacement plethysmography method for estimating percentage body fat in an elderly population: a comparison among compartmental models¹⁻³

Alice J Yee, Thomas Fuerst, Loren Salamone, Marjolein Visser, Maurice Dockrell, Marta Van Loan, and Marialice Kern

ABSTRACT

Background: The use of hydrostatic weighing (HW) to measure body composition in the elderly can be difficult and is based on the assumption of constancy of body compartments.

Objective: We calibrated and validated a new air-displacement plethysmography (AP) method for measuring body composition in the elderly.

Design: A 4-compartment equation for calculating percentage body fat (%BF) that used body density (D_b), total body water, and bone mineral content was used as the criterion for evaluating %BF estimated by the 2- and 3-compartment models. D_b was measured by HW [$D_{b(HW)}$] and by use of the AP instrument [$D_{b(AP)}$] in 30 elderly men and 28 elderly women aged 70–79 y.

Results: $D_{b(AP)}$ was not significantly different from $D_{b(HW)}$. However, analysis of variance showed a significant two-way interaction between sex and compartment model ($P < 0.02$), indicating that the comparisons between the sexes were different across all compartment models. The %BF calculated for the women was significantly higher than that calculated for the men by both HW and AP and for all compartment models.

Conclusion: Our data indicate that $D_{b(AP)}$ was not significantly different from $D_{b(HW)}$. Although differences were seen in %BF between the sexes, we observed no significant differences among the compartment models within each sex for this group of older individuals. *Am J Clin Nutr* 2001;74:637–42.

KEY WORDS Body composition, elderly, men, women, hydrostatic weighing, air-displacement plethysmography, multicompartiment models, body density, percentage body fat

INTRODUCTION

For an aging population, maintenance of skeletal muscle mass is important to retain the ability to perform daily activities (1). Body weight increases from the age of 20 to 50 y but declines after the age of 70 y (2, 3). Along with a gain in body weight, the fat-free body mass declines by 25–30% between the ages of 30 and 70 y (3, 4), while fat mass increases with age (5). Aside from the need to establish guidelines for percentage body fat (%BF) in the elderly, body-composition assessment methods that are quick, easy to use in elderly and other special populations, and provide results similar to those obtained with existing techniques need to be developed, calibrated, and validated.

Hydrodensitometry or hydrostatic weighing (HW), also known as underwater weighing, has been the criterion for body-composition measurement since the 1940s (6). HW requires complicated or often custom-made equipment, greater test times than do other methods, and a high degree of subject participation. Unlike HW, the air-displacement plethysmography (AP) instrument we used to measure body composition in the current study places fewer demands on the subject. There remains, however, a need to validate and calibrate this AP method, especially for special populations such as the elderly. Studies by Dempster and Aikens (7) and McCrory et al (8) in which this AP method was used reported that it is a valid and reliable method for assessing the volume of inanimate objects and of men and women aged 20–56 y. However, when examining elderly women, Bergsma-Kadijk et al (9) found that the estimation of %BF was 5% different between the 2-compartment (2C) and the 4-compartment (4C) model that used HW; they concluded that a 2C model was unacceptable compared with a 4C model in an elderly population.

Studies in which this AP instrument was used in an elderly population are lacking, and validity issues arise with the use of a 2C equation for comparison, which does not account for changes in bone mineral content (BMC) or total body water (TBW). The assumptions of the 2C model [that the density of the fat mass and fat-free mass (FFM) is constant] may not be appropriate for an elderly population (9–12). Therefore, this study had 2 purposes: 1) to compare body density (D_b) measured by the new AP instrument [$D_{b(AP)}$] with D_b measured by HW [$D_{b(HW)}$] in an elderly

¹From the Exercise Physiology Laboratory, the Department of Kinesiology, San Francisco State University; the Department of Radiology, University of California San Francisco; the Department of Epidemiology, the Graduate School of Public Health, University of Pittsburgh; the National Institute on Aging, the Epidemiology, Demography, and Biometry Program, Bethesda, MD; and the Western Human Nutrition Research Center, the US Department of Agriculture, University of California, Davis.

²Supported by the NIH (grant AG 62106) and the Research Infrastructure in Minority Institutions Program of the National Center for Research Resources with funding from the Office of Research on Minority Health of the NIH (grant RR11805-02).

³Address reprint requests to M Kern, Department of Kinesiology, 1600 Holloway Avenue, San Francisco State University, San Francisco, CA 94132. E-mail: mkern@sfsu.edu.

Received February 15, 2000.

Accepted for publication January 30, 2001.

population, and 2) to compare the 2C model with multicompart-ment models [3-compartment (3C) and 4C] of body-composition assessment in an elderly population.

SUBJECTS AND METHODS

Subjects

Thirty men and 30 women aged 70–79 y were recruited by the University of California, San Francisco, through advertisements placed in the university and local communities and by contact with senior citizen organizations in the area. Informed consent of the subjects was obtained before their participation in the study. The study was performed in accordance with the Committee for the Protection of Human Subjects at San Francisco State University. The subjects were required to be healthy 70–79-y-old adults who could walk up a flight of stairs and submerge themselves completely underwater. Subjects were recruited to fill 3 categories of body mass index (BMI; in kg/m²): 1) normal weight (BMI = 21–24), 2) overweight (BMI = 25–29), and 3) obese (BMI ≥ 30) (13). The final distribution of subjects across the BMI categories was ≈25%, 50%, and 25%, respectively. The study required 1 session per individual. At each session, height, weight, D_b (measured by HW or the AP instrument), residual volume (RV), TBW, and BMC were measured. BMC and TBW were measured at the University of California, San Francisco. All other measurements were done at San Francisco State University. Dry measurements were performed first and HW last. Each session began in the morning and lasted ≈5–6 h and was done after the participants fasted overnight (14).

Residual volume

RV was measured by a helium rebreathing technique performed on a Collins SVR/PLUS (Braintree, MA) with a functional residual capacity test. With the mouthpiece in place, the subject was asked to breathe normally until the spirometer equilibrated. After equilibration, the subject performed a maximal inspiration followed by a forced maximal exhalation, which allowed inspiratory and expiratory reserve capacity to be measured, respectively. RV was calculated as the functional residual capacity minus the expiratory reserve capacity (15). For more consistent results, the subject performed this procedure 3 times with 5 min of rest between each test. Carbon dioxide absorbant and dessicant were checked and, if necessary, changed during the rest periods. The same examiner was used for all subjects. The average of the 3 tests was used as the calculation of RV.

Hydrostatic weighing

D_b was measured while participants wore bathing suits and sat on a chair suspended in a fiberglass tank. The subjects were asked to submerge themselves underwater and perform a forced exhalation. Subjects repeated this task 10 times. Measurements were taken with an autopsy scale and were recorded to the nearest 0.01 kg. The average of the 3 highest weights was used for the calculation of D_b .

Body mass index

Height was measured to the nearest 0.1 cm and weight was measured to the nearest 0.1 kg on a calibrated Detecto weight scale (Cardinal Scale Manufacturing Company, Webb City, MO). BMI was calculated in kg/m² (16).

Air-displacement plethysmography

The Bod Pod body-composition system (Life Measurement, Inc, Concord, CA) was also used to measure D_b . Body weight, body volume, and thoracic lung volume were measured for each subject by using a dual-chambered plethysmograph, an electronic weigh scale, and BOD POD software, version 1.0 (Life Measurement, Inc) as described by McCrory et al (8).

Bone mineral content

BMC was measured by using a QDR-4500A bone densitometer (Hologic Inc, Waltham, MA) with a fan beam array. All scans were performed and analyzed with the instrument's proprietary software (version 8.21, Hologic Inc) at the University of California, San Francisco, by the same technician according to the standard operating procedures recommended by the manufacturer (17).

Total body water

Deuterium dilution was used to measure TBW. A baseline venipuncture plasma sample was taken at the beginning of testing. A measured amount of deionized water and deuterium (0.1 g ²H₂O/estimated kg TBW) was taken orally by each subject. A final venipuncture plasma sample was taken at the end of the study ≥4 h after dosing to ensure equilibration of the deuterium with the body water. Subjects were not allowed to have any food or beverages during the 4-h equilibration period. The samples were frozen and shipped to the University of Chicago for analysis of TBW (18).

Percentage body fat equations

D_b measured by HW and by the AP instrument were compared in the 4C, 3C, and 2C equations. The 2C_{AP} %BF and BMC results were automatically reported by the proprietary software of these devices, whereas the results for HW required additional calculations (19). The following %BF equations were used:

Siri's 2C and 3C models (16, 17) and Selinger's 4C model (16).

$$2C_{HW} = \%BF \text{ from HW with use of Siri's equation} \\ = \{ [4.95/D_{b(HW)}] - 4.50 \} \times 100 \quad (1)$$

$$2C_{AP} = \%BF \text{ from AP with use of Siri's equation} \\ = \{ [4.95/D_{b(AP)}] - 4.50 \} \times 100 \quad (2)$$

$$3C_{BMCHW} = \%BF \text{ corrected for BMC and HW with} \\ \text{use of Siri's mineral density formula} \\ = \{ [6.386/D_{b(HW)}] + [3.961 \times m] - 6.090 \} \\ \times 100 \quad (3)$$

$$3C_{TBWHW} = \%BF \text{ corrected for TBW and HW with} \\ \text{the use of Siri's TBW formula} \\ = \{ [2.118/D_{b(HW)}] - [0.78 \times w] - 1.354 \} \times 100 \quad (4)$$

$$3C_{BMCAP} = \%BF \text{ corrected for BMC and AP with the} \\ \text{use of Siri's mineral density formula} \\ = \{ [6.386/D_{b(AP)}] + [3.961 \times m] - 6.090 \} \\ \times 100 \quad (5)$$

$$3C_{TBWAP} = \%BF \text{ corrected for TBW and AP with the} \\ \text{use of Siri's TBW formula} \\ = \{ [2.118/D_{b(AP)}] - [0.78 \times w] - 1.354 \} \\ \times 100 \quad (6)$$

TABLE 1
Subject characteristics¹

| Variable | All (n = 58) | Men (n = 30) | Women (n = 28) |
|--------------------------|-----------------|-----------------|------------------------------|
| Age (y) | 73.1 ± 2.24 | 73.4 ± 2.14 | 72.8 ± 2.34 |
| Height (cm) | 166.4 ± 9.43 | 173.2 ± 6.03 | 159.1 ± 6.39 ² |
| Weight (kg) | 75.9 ± 14.87 | 83.7 ± 12.21 | 67.5 ± 12.86 ² |
| BMI (kg/m ²) | 27.3 ± 4.28 | 27.8 ± 3.35 | 26.7 ± 5.09 |
| TBW (L) | 36.9 ± 7.92 | 43.0 ± 5.16 | 30.5 ± 4.55 ² |
| BMC (g) | 2276.2 ± 547.56 | 2670.6 ± 409.54 | 1853.5 ± 307.75 ² |
| D _{b(HW)} | 1.0239 ± 0.0192 | 1.0377 ± 0.0124 | 1.0091 ± 0.0132 ² |
| D _{b(AP)} | 1.0223 ± 0.0191 | 1.0351 ± 0.0135 | 1.0087 ± 0.0140 ² |

¹ $\bar{x} \pm SD$. TBW, total body water; BMC, bone mineral content; D_{b(HW)}, body density measured by hydrostatic weighing; D_{b(AP)}, body density measured by air-displacement plethysmography.

²Significantly different from men, P < 0.05.

$$4C_{HW} = \%BF \text{ from HW with the use of Selinger's equation} \\ = \{ [2.747/D_{b(HW)}] - [0.714 \times w] + [1.146 \times m] - 2.0503 \} \times 100 \quad (7)$$

$$4C_{AP} = \%BF \text{ from AP with the use of Selinger's equation} \\ = \{ [2.747/D_{b(AP)}] - [0.714 \times w] + [1.146 \times m] - 2.0503 \} \times 100 \quad (8)$$

where w is TBW as %BF and m is BMC as %BF.

Statistics

Pearson's correlation coefficient was used to determine the relation between D_{b(HW)} and D_{b(AP)}. A three-way analysis of variance was used to determine significant differences in main effects and interactions. Analyses were adjusted for multiple pairwise comparisons by using Bonferroni's post hoc test. The values are reported as means ± SDs. Line plots were used for graphical purposes to denote linearity and homogeneity of the group. STATISCA version 5.0 (Stat Soft, Tulsa, OK) was used for statistical analyses. A probability level of <0.05 was used to determine statistical significance.

RESULTS

Two women were eliminated from the data set because of their inability to properly perform the forced exhalation underwater and the adequate number of submergences. As expected, D_b was significantly different between the men and women (Table 1), but D_{b(HW)} was not significantly different from D_{b(AP)}. As also shown in Table 1, age and BMI were not significantly different between the sexes; all other variables were significantly different between the men and women.

The mean TBW for all subjects combined was 36.9 ± 7.92 L for TBW. The ratio of TBW to FFM (TBW/FFM) was 71.5%, slightly below the accepted standard of ≈73% (20). The average TBW for men was 43.0 ± 5.16 L and TBW/FFM was 70.4%. In women, TBW averaged 30.50 ± 4.55 L and TBW/FFM was 76.1%. The BMC for men and women combined was 2276.2 ± 547.56 g, giving a ratio of BMC to FFM (BMC/FFM) of 4.5%. The reference norm for BMC/FFM is 6.8% ± 0.9% (16). BMC was higher in the men than in the women (2670.6 ± 409.54 compared with 1853.5 ± 307.75 g), resulting in a lower BMC/FFM in the men

(4.4% compared with 4.6% of the reference norm of 6.8% in men and women, respectively).

No significant differences were observed in %BF for the main effects of sex, method, or compartment model. However, a significant interaction was observed for sex by compartment models. %BF was significantly higher for the women than the men in all compartment models (Table 2).

Pearson's correlation coefficients (Table 3) were used to examine the association between %BF from HW and AP, as well to compare the 2C equations with the multicompartiment equations. The correlation coefficient for D_{b(HW)} compared with D_{b(AP)} was r = 0.91 for both sexes combined, 0.74 for men, and 0.89 for women. Not surprisingly, the combination of the sexes yielded higher correlations because of the larger sample size and the heterogeneity of the group, which consequently created a greater range in the data (Figures 1–3 and Table 3).

DISCUSSION

In this group of elderly men and women, no significant differences were found between D_b measured by either HW or the AP instrument. This agrees with the results of the study conducted by McCrory et al (8) in which the 2C_{AP} model was as valid and reliable as the 2C_{HW} model. No significant differences were found between the first and second trials when AP was compared with HW. Dempster and Aitkens (7) showed in their study, which used inanimate objects, excellent reliability with repeated measures. A between-day analysis that was done by using 1 cylinder and 20 trials yielded a %BF error of 0.1%. When 5 sequential measures were performed with the use of different volumes (25, 50, 75, 100, 125, and 150 mL), a linear plot was drawn with r² = 1.00. This however, does not eliminate the possible effect of TBW and BMC on the calculation of %BF in the multicomponent models.

Significant differences were found in the interaction of the compartment models (2C, 3C, and 4C equations) and sex (men and women). Within a sex group, the compartment models did not differ in the estimation of %BF; however, between the sexes the estimates of %BF for all compartment models were different: the women had higher %BF than the did the men. These findings differ from the results reported by Bergsma-Kadijk et al (9) in which the 2C and 3C compartment models were significantly

TABLE 2
Percentage body fat as calculated with use of the different body-composition models¹

| Models | All (n = 58) | Men (n = 30) | Women ² (n = 28) |
|--------------------------------|-----------------|-----------------|--------------------------------|
| 4C _{HW} | 31.8 ± 8.98 | 26.5 ± 6.12 | 37.5 ± 8.03 |
| 4C _{AP} | 32.2 ± 9.03 | 27.1 ± 6.51 | 37.7 ± 8.20 |
| 3C _{BMC_{HW}} | 26.8 ± 10.54 | 19.2 ± 6.69 | 35.0 ± 7.26 |
| 3C _{TBW_{HW}} | 33.3 ± 8.71 | 28.4 ± 6.00 | 38.6 ± 8.10 |
| 3C _{BMC_{AP}} | 27.8 ± 10.30 | 20.8 ± 7.10 | 35.3 ± 7.53 |
| 3C _{TBW_{AP}} | 33.6 ± 8.77 | 28.9 ± 6.33 | 38.7 ± 8.24 |
| 2C _{HW} | 33.6 ± 9.07 | 27.1 ± 5.70 | 40.6 ± 6.39 |
| 2C _{AP} | 34.4 ± 8.99 | 28.3 ± 6.22 | 40.9 ± 6.62 |

¹ $\bar{x} \pm SD$. 4C, 4 compartment; 3C, 3 compartment; 2C, 2 compartment, HW, hydrostatic weighing; AP, air-displacement plethysmography; BMC, bone mineral content; TBW, total body water.

²For all values, there was a significant sex by compartment model interaction, P < 0.05.



TABLE 3Pearson's correlation coefficients for the relations between methods used to calculate percentage body fat¹

| | 2C _{HW} | 3C _{BMCHW} | 3C _{TBWHW} | 2C _{AP} | 3C _{BMCAP} | 3C _{TBWAP} | 4C _{AP} | 4C _{HW} |
|---------------------|------------------|---------------------|---------------------|-------------------|---------------------|---------------------|-------------------|-------------------|
| All | | | | | | | | |
| 2C _{HW} | 1.00 | 0.99 ² | 0.89 ² | 0.91 ² | 0.91 ² | 0.84 ² | 0.86 ² | 0.91 ² |
| 3C _{BMCHW} | | 1.00 | 0.88 ² | 0.88 ² | 0.89 ² | 0.82 ² | 0.84 ² | 0.91 ² |
| 3C _{TBWHW} | | | 1.00 | 0.87 ² | 0.88 ² | 0.98 ² | 0.98 ² | 0.99 ² |
| 2C _{AP} | | | | 1.00 | 0.99 ² | 0.90 ² | 0.92 ² | 0.88 ² |
| 3C _{BMCAP} | | | | | 1.00 | 0.90 ² | 0.92 ² | 0.89 ² |
| 3C _{TBWAP} | | | | | | 1.00 | 1.00 ² | 0.97 ² |
| 4C _{AP} | | | | | | | 1.00 | 0.97 ² |
| 4C _{HW} | | | | | | | | 1.00 |
| Men | | | | | | | | |
| 2C _{HW} | 1.00 | 0.98 ² | 0.86 ² | 0.74 ² | 0.73 ² | 0.74 ² | 0.74 ² | 0.89 ² |
| 3C _{BMCHW} | | 1.00 | 0.85 ² | 0.66 ² | 0.68 ² | 0.70 ² | 0.71 ² | 0.88 ² |
| 3C _{TBWHW} | | | 1.00 | 0.81 ² | 0.82 ² | 0.96 ² | 0.95 ² | 1.00 ² |
| 2C _{AP} | | | | 1.00 | 0.99 ² | 0.90 ² | 0.91 ² | 0.79 ² |
| 3C _{BMCAP} | | | | | 1.00 | 0.91 ² | 0.93 ² | 0.81 ² |
| 3C _{TBWAP} | | | | | | 1.00 | 1.00 ² | 0.94 ² |
| 4C _{AP} | | | | | | | 1.00 | 0.93 ² |
| 4C _{HW} | | | | | | | | 1.00 |
| Women | | | | | | | | |
| 2C _{HW} | 1.00 | 0.98 ² | 0.83 ² | 0.89 ² | 0.88 ² | 0.79 ² | 0.81 ² | 0.85 ² |
| 3C _{BMCHW} | | 1.00 | 0.81 ² | 0.84 ² | 0.86 ² | 0.77 ² | 0.79 ² | 0.85 ² |
| 3C _{TBWHW} | | | 1.00 | 0.80 ² | 0.80 ² | 0.99 ² | 0.98 ² | 1.00 ² |
| 2C _{AP} | | | | 1.00 | 0.99 ² | 0.84 ² | 0.86 ² | 0.81 ² |
| 3C _{BMCAP} | | | | | 1.00 | 0.84 ² | 0.86 ² | 0.81 ² |
| 3C _{TBWAP} | | | | | | 1.00 | 1.00 ² | 0.98 ² |
| 4C _{AP} | | | | | | | 1.00 | 0.98 ² |
| 4C _{HW} | | | | | | | | 1.00 |

¹2C, 2 compartment; 3C, 3 compartment; 4C, 4 compartment; HW, hydrostatic weighing; BMC, bone mineral content; TBW, total body water; AP, air-displacement plethysmography.

² $P < 0.05$.

different from the 4C model when tested on elderly women. A review by Heymsfield et al (21) analyzed measured compared with calculated densities of the 4 compartments of the body: fat, water, protein, and minerals. They concluded that the 4C model accounted for >97% of the total body weight whether the densities were calculated or measured. By contrast, a 2C model was not able to yield such a high percentage because of the assumptions of a 2C model and a steady decline in total body calcium, potassium (minerals), and protein for both elderly men and women after the age of 25 y (21).

As shown in Table 2, the older individuals had a greater %BF than the younger ones, which was compounded by the loss of FFM or sarcopenia in the older individuals (9, 13). The mean %BF in this population with the use of the 4C model was $26.75 \pm 6.31\%$ for the men and $37.6 \pm 8.11\%$ for the women. The men had a %BF >44% greater than that of the reference man, which is normally considered to be 15%BF. The women had a %BF >33% greater than that of the reference woman, which is normally 25%BF (13). These elevated amounts of %BF are similar to those previously reported in the literature (13).

Declining BMC (21, 22) and fluctuations of TBW (23, 24) are not uncommon in the elderly (25). First, other studies showed that BMC was $\approx 6.8 \pm 0.9\%$ of FFM (16). This would yield a predicted BMC of 3410 ± 450 g given the FFM of this elderly population. In this study, the BMC was 2276 ± 547 g. This is 2.5 SDs below the reference value of 6.8% of FFM. The lower BMC in our study population may have been due to the calibration of the QDR-4500A bone densitometer or may represent the actual bone mineral status of this elderly population.

Age-related bone loss likely led to a lower BMC in the elderly men and women studied here. Consequently, the fraction of total FFM that is represented by BMC will be lower than that seen in a younger population.

The bone mineral calibration of the QDR-4500A bone densitometer has been compared with previous models (17). In general, close agreement (mean differences of <1–2%) was seen

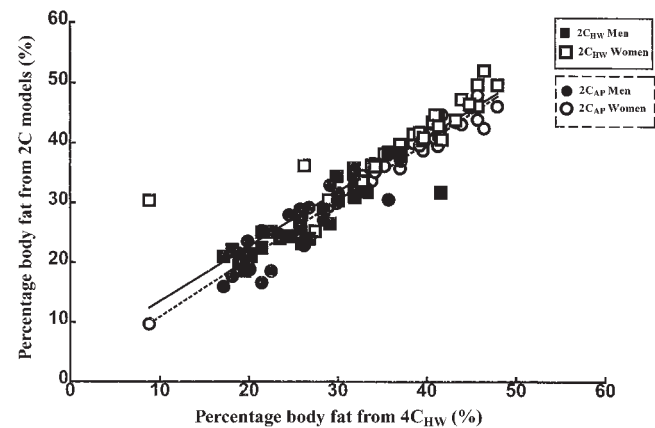


FIGURE 1. Scatter plot of the relation between percentage body fat measured by the 2-compartment (2C) models and that measured by the 4-compartment (4C) equation. HW, hydrostatic weighing; AP, air-displacement plethysmography instrument. $2C_{HW} = 0.9225x + 0.0428$, $R = 0.91$. The equations used to calculate percentage body fat are given in the text.

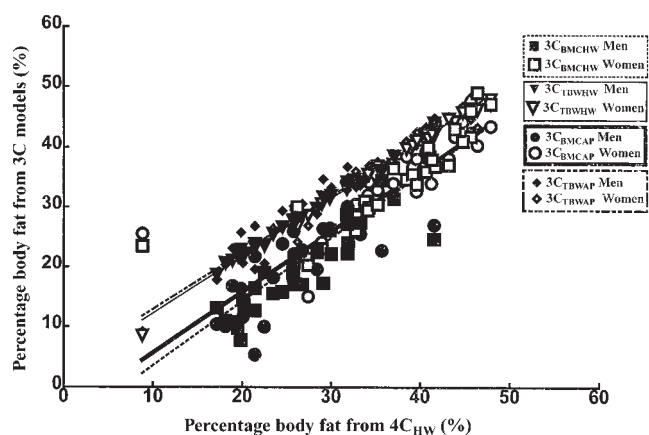


FIGURE 2. Scatter plot of the relation between percentage body fat measured by the 3-compartment (3C) models and that measured by the 4-compartment (4C) equation. BMC, bone mineral content; HW, hydrostatic weighing; TBW, total body water; AP, air-displacement plethysmography instrument. $3C_{BMCHW} = 1.0675x + 0.0712$, $R = 0.91$; $3C_{TBWHW} = 0.9666x + 0.0255$, $R = 0.99$; $3C_{BMCAP} = 1.0158x + 0.0452$, $R = 0.89$; $3C_{TBWAP} = 0.9495x + 0.0342$, $R = 0.97$. The equations used to calculate percentage body fat are given in the text.

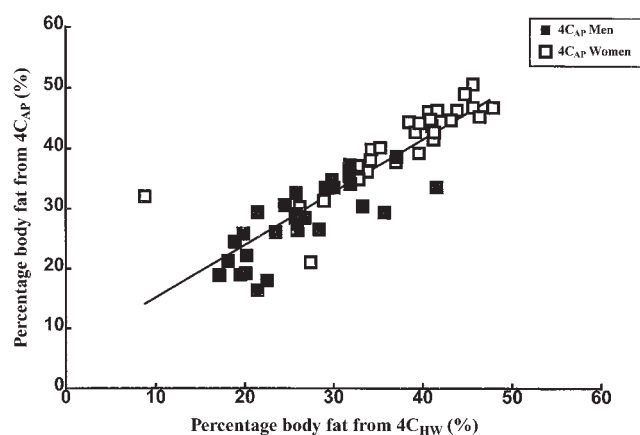


FIGURE 3. Scatter plot of the relation between percentage body fat measured by the 4-compartment (4C) model with hydrostatic weighing (HW) and that measured by the 4C model with the air-displacement plethysmography (AP) instrument. $4C_{AP} = 0.9778x + 0.0112$, $R = 0.97$. The equations used to calculate percentage body fat are given in the text.


when the bone mineral density results of the spine, femur, or forearm from the QDR-4500A bone densitometer were compared with those from earlier Hologic models. However, 2 studies showed that the total body BMC measured by the QDR-4500A bone densitometer is 5–6% lower than that observed with the QDR-2000 (26) and QDR-1000 bone densitometers (27).

Second, TBW varies with age and FFM (24). It is commonly believed that the older the individual the less body water he or she has because of higher body fat or reduced hydration (13). However, Schoeller and Jones (24) noted that with advancing age overall hydration remains constant and may become even slightly higher, suggesting that the hydration status of the elderly was not a factor that affected body composition.

The human body, if normally hydrated, consists of 73% of FFM as water (24, 26). Consequently, if this elderly group were normally hydrated, the TBW should be ≈ 37 L; in fact, the average measured TBW for this sample was 36.94 ± 7.92 L. Changes in hydration amounts with advancing age are currently unknown. Some researchers have reported dehydration among elderly individuals (13, 16), whereas others have not (24). Our results suggest that this group of elderly individuals was not dehydrated, which allows us to conclude that the 2C water estimations are valid.

Addition of the BMC to the 3C model (Figure 2) resulted in no significant difference in the estimate of %BF compared with the 2C (Figure 1), $3C_{TBW}$, and 4C (Figure 3) models. Thus, the addition of TBW (Figure 2) did not result in a significant difference in the estimation of %BF in either the 3C or 4C models. Furthermore, the combination of BMC and TBW in the 4C model did not result in an estimate of %BF significantly different from that of any of the other models.

In conclusion, HW has drawbacks when used in an elderly population. The tests are time consuming and the subjects must be in good physical condition to perform the procedure. The new AP instrument was faster, less physically challenging for the participants, and provided results that were not significantly different

from those obtained with traditional HW. Finally, the use of multicompartments did not provide estimates of %BF significantly different from those obtained by the 2C model in this particular group of older individuals. 

We thank Frank Verducci of San Francisco State University for his knowledge, expertise, and support of this project.

REFERENCES

1. Marks BL, Rippe JM. The importance of fat free mass maintenance in weight loss programmes. *Sports Med* 1996;22:273–81.
2. Borkan GA, Hults DE, Gerzof SG, Robbins AH, Silbert CK. Age changes in body composition revealed by computed tomography. *J Gerontol* 1983;38:673–7.
3. Bembien MG, Massey BH, Bembien DA, Boileau RA, Misner JE. Age-related patterns in body composition for men aged 20–79 yr. *Med Sci Sports Exerc* 1995;27:264–9.
4. Grimby G, Saltin B. Mini review: the aging muscle. *Clin Physiol* 1983;3:209–18.
5. Poehlman ET, Toth MJ, Bunyard LB, et al. Physiological predictors of increasing total and central adiposity in aging men and women. *Arch Intern Med* 1995;155:2443–8.
6. Behnke AR, Wilmore JH. The specific gravity of healthy men. *JAMA* 1942;118:495–8.
7. Dempster P, Aitkens S. A new air displacement method for the determination of human body composition. *Med Sci Sports Exerc* 1995;27:1692–7.
8. McCrory MA, Gomez TD, Bernauer EM, Mole PA. Evaluation of a new air displacement plethysmograph for measuring human body composition. *Med Sci Sports Exerc* 1995;27:1686–91.
9. Bergsma-Kadijk J, Baumeister B, Deurenberg P. Measurement of body fat in young and elderly women: comparison between a four-compartment model and widely used reference methods. *Br J Nutr* 1996;75:649–57.
10. Forslund AH, Johansson AG, Sjodin A, Brydning G, Ljunghall S, Hambraeus L. Evaluation of modified multicompartments models to calculate body composition in healthy males. *Am J Clin Nutr* 1996; 63:856–62.
11. Pace N, Rathbun EN. Studies on body composition III. The body water and chemically combined nitrogen content in relation to fat content. *J Biol Chem* 1945;158:685–91.

12. Friedl KE, DeLuca JP, Marchitelli LJ, Vogel JA. Reliability of body-fat estimations from a four-compartment model by using density, body water, and bone mineral measurement. *Am J Clin Nutr* 1992; 55:764–70.
13. Spirduso WW. Physical development and decline. In: *Physical dimensions of aging*. Champaign, IL: Human Kinetics, 1995: 57–86.
14. Thomas TR, Crough LD, Araujo J. Dietary preparation and percentage fat measurement by hydrostatic weighing. *Br J Sports Med* 1988;22:9–11.
15. Charniak RM. Assessment of ventilatory function. In: *Pulmonary function testing*. Philadelphia: WB Saunders, 1992:135–43.
16. Lohman TG. *Advances in body composition assessment*. Champaign, IL: Human Kinetics, 1992.
17. Fuerst T, Gluer CC, Genant HK. Performance evaluation of a new bone densitometer: Hologic QDR-4500. *J Bone Miner Res* 1995; 10(suppl):S370 (abstr).
18. Schoeller DA, Hnilicka JM. Reliability of the doubly labeled water method for the measurement of total daily energy expenditure in free-living subjects. *J Nutr* 1996;126(suppl):S348–54.
19. Heyward V. *Advanced fitness assessment and exercise prescription*. 2nd ed. Champaign, IL: Human Kinetics, 1991.
20. Hewitt MJ, Going SB, Williams DP, Lohman TP. Hydration of the fat-free body mass in children and adults: implications for body composition assessment. *Am J Physiol* 1993;265:E88–95.
21. Heymsfield SB, Wang J, Lichtman S, Kamen Y, Kehayias J, Pierson RN Jr. Body composition in elderly subjects: a critical appraisal of clinical methodology. *Am J Clin Nutr* 1989;50:1167–75.
22. Ooms ME, Lips P, Van Lingen A, Valkenburg HA. Determinants of bone mineral density and risk factors for osteoporosis in healthy elderly women. *J Bone Miner Res* 1993;8:669–75.
23. Steen GB, Isaksson B, Svanberg A. Body composition at 70 and 75 years of age: a longitudinal population study. *J Clin Exp Gerontol* 1979;1:185–200.
24. Schoeller DA, Jones PJH. Changes in total body water with age. *Am J Clin Nutr* 1989;50:1176–81.
25. Chumlea WC, Baumgartner RN. Status of anthropometry and body composition data in elderly subjects. *Am J Clin Nutr* 1989;50: 1158–66.
26. Fuerst T, Genant HK. Evaluation of body composition and total body bone mass with the Hologic QDR-4500. *Osteoporos Int* 1996; 6(suppl):S202 (abstr).
27. Bouyoucef SE, Cullum ID, Ell PJ. Cross-calibration of a fan-beam X-ray densitometer with a pencil-beam system. *Br J Radiol* 1996; 69:522–31.

