Ellis, Kenneth J., and William W. Wong. Human hydrometry: comparison of multifrequency bioelectrical impedance with \(^{2}H_2O\) and bromine dilution. J. Appl. Physiol. 85(3): 1056–1062, 1998.—The traditional method of assessing total body water (TBW), extracellular water (ECW), and intracellular water (ICW) has been the use of isotopes, on the basis of the dilution principle. Although the development of bioelectrical impedance techniques has eliminated many of the measurement constraints associated with the dilution methods, the degree of interchangeability between the two methods remains uncertain. We used multifrequency bioelectrical impedance spectroscopy (BIS), \(^{2}H_2O\) dilution, and bromine dilution to assess TBW, ECW, and ICW in 469 healthy subjects (248 males, 221 females) aged 3–29 yr. We found that the TBW, ECW, and ICW estimates for the BIS and dilution methods were significantly correlated \((r^2 = 0.80–0.96, P < 0.0001, SE\) of the estimate = 2.3–2.7 liters). On the basis of population, the constants used in the BIS analysis could be adjusted so that the mean differences with the dilution methods would become zero. The SD values for the mean differences between the dilution and BIS methods, however, remained significant for both males and females: TBW (±2.1–2.8 liters), ECW (±1.4–1.6 liters), and ICW (2.0–3.1 liters). To improve the accuracy of the BIS measurement for an individual within the age range we have examined, further refinement of the constants used in the BIS analysis is needed.

Total body water; extracellular water; intracellular water; children; adults

BODY WATER IS THE HIGHEST fractional content of body weight, except in cases of extreme obesity. Body water is also the most abundant component of the fat-free mass (FFM) and remains relatively constant once adulthood is reached. Changes in the hydration status of the FFM, however, are part of the basic physiology of growth and appear to be part of the aging process in later life (7, 9). Both acute and chronic changes in hydration also can occur during various diseases and their clinical management. A major challenge in the science of body composition research has been to accurately monitor these changes, whether in healthy or diseased subjects. The classic approach for the measurement of total body water (TBW) has been the use of radioactive or stable isotopes (e.g., tritium, \(^{3}H_2O\), oxygen-18) of water, on the basis of the dilution principle (20, 21, 29).

The distribution of water in the FFM can be further divided into two major physiological or cellular components: intracellular water (ICW) and extracellular water (ECW). The volume of the ECW compartment also has been estimated by using the dilution technique with bromine (Br), chlorine, and sucrose tracers (18, 30, 31). When TBW and ECW are known, the ICW volume has been defined as their difference. In the healthy state, the body’s water distribution (e.g., relative ratios of ECW to TBW or ICW) appears to be tightly regulated. In an abnormal state, these ratios can be significantly altered and are often attributable to an elevated ECW, whereas the ICW volume can remain relatively normal or reduced.

Until recently, the routine assessments of TBW and ECW could only be determined by dilution techniques (20) or on the basis of a multicompartment body composition model that required neutron-activation analysis (28). In either case, repeat measurements were difficult, if not impossible, to achieve. Repeat measurements by using the dilution method required either a waiting period while the tracers cleared from the body or the use of higher doses. In addition, the analytic procedures needed for processing of the fluid samples are time-consuming (routinely requiring days or weeks), which eliminates their use for immediate assessment of a subject. With the advent of bioelectrical impedance technology, many of these restrictions have been eliminated (4, 15). The ability to perform frequent, rapid, noninvasive measurements with bioelectrical impedance techniques is a major advantage of this technology, making it especially appealing for use in children.

Initial studies of the bioelectrical impedance analysis (BIA) method used a single-frequency measurement technique, typically at 50 kHz (16). This single-frequency BIA technique has been examined extensively, and its application in the nonhealthy state has been seriously questioned (4, 17). Subsequently, the single-frequency technique was extended to measurements by using a full range of frequencies (1 kHz to 1.35 MHz) and is known as bioelectrical impedance spectroscopy (BIS). Although a number of studies have reported comparisons between the dilution method and the single-frequency BIA technique (13, 24), only a few studies have compared the dilution method to BIS (2–4, 8, 17). Only one study has reported a systematic assessment of BIS vs. the dilution method in children (22).

The objective of the present study was to compare the BIS-derived estimates for TBW, ECW, and ICW with those based on the dilution methods. We particularly wanted to determine whether substitution of BIS for the dilution methods would continue to provide accurate assessments of these three water compartments in an individual.

METHODS

Subjects. A group of 469 subjects, consisting of 387 children (172 boys, 215 girls, age 3–18 yr) and 82 young adults (49
men, 33 women, age 19–29 yr), participated in this study. Subjects were from three ethnic groups (white, black, Hispanic). Body weight was measured by using an electronic balance to ±0.2 kg; height was measured by using a stadiometer to ±0.3 cm. The study was approved by the Institutional Review Board for Human Research at Baylor College of Medicine, and written informed consent was obtained for each subject.

Dilution measurements. TBW was measured by using $^{2}$H$_{2}$O dilution (29). After providing a baseline blood sample, the subject drank water containing $^{2}$H$_{2}$O at a dose of 70 mg $^{2}$H$_{2}$O/kg body weight. Three to four hours after the oral dose, a second blood sample was obtained. Plasma was separated from the blood samples and frozen at −70°C for later analysis. $^{2}$H$_{2}$O enrichment was determined in plasma by isotope-ratio mass spectroscopy (29). The baseline (0 h) value was used to correct the background $^{2}$H$_{2}$O concentration value for the 3- to 4-h sample. All assays were performed in duplicate, and repeat assays indicated an analytical precision of ±2%. The calculation of TBW can be described by the following equation

$$TBW = \frac{[^{2}H_{2}O] \text{dose}}{[^{2}H_{2}O]_{0h} - [^{2}H_{2}O]_{3h}} / 1.04$$

(1)

where $[^{2}H_{2}O]$ denotes plasma concentration, and the constant (1.04) was used to adjust for exchange of $^{2}$H$_{2}$O with nonexchangeable hydrogen in the body.

The measurement of ECW was determined by using Br dilution (30). NaBr was added to the oral $^{2}$H$_{2}$O dose such that the subject received 30 mg Br/kg body weight. Serum samples were obtained from the baseline and 3- to 4-h blood samples, frozen, and later assayed by using an HPLC anion-exchange method, after serum ultrafiltration (30). ECW was calculated as

$$ECW = \frac{[Br] \text{dose}}{[Br]_{0h} - [Br]_{3h}} \times 0.90 \times 0.95$$

(2)

where [Br] denotes the serum Br concentration, and the constants (0.90, 0.95) are used to adjust for the overexpansion of Br into nonextracellular sites and for the Donnan equilibrium effect. Duplicate samples within an assay were performed with an analytic precision ±2–3%; intra-assay precision was <3%. ICW volume was defined as

$$ICW = TBW - ECW$$

(3)

RESULTS

Table 1 provides the anthropometric characteristics of the study population, subdivided by gender and ethnicity. The results for the TBW, ECW, and ICW compartments, obtained by the $^{2}$H$_{2}$O- and Br-dilution methods, are included in Table 1. ANOVA indicated that, for the body water compartments, there were no differences among ethnic groups within a gender group. There were significant differences (P < 0.0001) for TBW and ICW but not for ECW, between males and females.

Table 2 provides the mean and SD values for $V_{TBW}$, $V_{ECF}$, and $V_{ICF}$ for each gender and ethnic subgroup when the BIS method was used. ANOVA detected no differences for $V_{TBW}$, $V_{ECF}$, and $V_{ICF}$ among ethnic subgroups within a gender classification. The mean
values for $V_{TBW}$, $V_{ECF}$, and $V_{ICF}$ were significantly different between males and females. The correlations between $ECW$ and $V_{ECF}$ were significant for males ($r^2 = 0.84, P < 0.0005$, SEE = 2.3 liters) and females ($r^2 = 0.84, P < 0.0005$, SEE = 2.3 liters). Figure 1 provides a plot of the difference ($ECW_{diff} = V_{ECF} - ECW$) vs. the average values for the two methods. For males, the distribution of $ECW_{diff}$ values was independent of the average values ($r^2 = 0.01, P > 0.2$). For females, the individual $ECW_{diff}$ values became more negative with increasing average values ($r^2 = 0.06, P < 0.01$). It is also evident in Fig. 1 that a number of subjects had $ECW_{diff}$ values that were substantially displaced (outside ± 2 SD) from the mean differences for the total population. Repeat assays of stored serum samples and a reexamination of the goodness-of-fit parameters provided by the BIS analysis did not identify any clear technical reasons to eliminate these data. The value for $ECW_{diff}$ for males was 0.25 ± 1.36 (SD) liters and was significantly different ($P < 0.001$) from the value of -0.63 ± 1.59 liters for females. Similar differences were obtained for each of the ethnic subgroups and are provided in Table 2. When the difference values were expressed as a percentage of the average value [$ECW_{diff} = 100 \times (ECW_{diff}/average ECW)$], the $ECW_{diff}$ values for both males and females were independent of the average values. The values for $ECW_{diff}$ were 0.1 ± 19.1 (SD) % for males and −6.5 ± 16.3% for females.

For the ICW compartment, the results for the dilution methods and BIS measurements were also significantly correlated for males ($r^2 = 0.85, P < 0.0005$, SEE = 2.5 liters) and females ($r^2 = 0.85, P < 0.0005$, SEE = 2.5 liters). The slope and intercept values, however, were statistically ($P < 0.001$) different from the line of identity. Figure 2 provides a plot of the difference values ($ICW_{diff} = V_{ICF} - ICW$) vs. the average values for the two methods for males and females. It is clearly evident that the $ICW_{diff}$ values are not independent of the average values but significantly decrease as the average values increase (males: $r^2 = 0.35, P < 0.0001$; females: $r^2 = 0.13, P < 0.001$). The value for $ICW_{diff}$ for males was −2.79 ± 3.05 (SD) liters and was significantly different ($P < 0.001$) from the value of −1.80 ± 0.01 liters for females. When the $ICW_{diff}$ values were expressed as a percentage of the average value [$ICW_{diff} = 100 \times (ICW_{diff}/average ICW)$], the $ICW_{diff}$ values were independent of the average values. The values for $ICW_{diff}$ were −18.1 ± 21.0 (SD) % for males and −15.3 ± 19.5% for females.

The relationship between $TBW$ and $V_{TBW}$ was also highly correlated ($r^2 = 0.95, P < 0.0005$, SEE = 2.7 liters for males and females).
liters). However, the BIS-derived $V_{TBW}$ values were consistently lower than those obtained by the $^2$H$_2$O-dilution method. Figure 3 provides a plot of the difference values ($TBW_{diff} = V_{TBW} - TBW$) vs. the average values for the two methods for males and females. Regression analyses indicate that the $TBW_{diff}$ values significantly decreased with increasing average values for males ($r^2 = 0.21$, $P < 0.001$) but not for females ($r^2 = 0.01$, $P > 0.2$). The values for $TBW_{diff}$ were $-2.70 \pm 2.80$ (SD) liters for males and $-2.39 \pm 2.13$ liters for females. When the difference values were expressed as a percentage of the average value ($TBW_{%diff} = \frac{TBW_{diff}}{average\ TBW} \times 100$), the $TBW_{%diff}$ values were independent of the average values. In this case, the value was $-9.2 \pm 9.2$ (SD) % for $ICW_{%diff}$ for both males and females.

A summary of the mean differences ± SD between the dilution and BIS methods for each gender and the three ethnic subgroups is provided in Table 2. The mean values for $TBW_{diff}$ and $ICW_{diff}$ were significantly different from zero ($P < 0.0005$) for each gender and ethnic subgroup. The $TBW_{diff}$ values for males were significantly greater ($P < 0.02$) than were the corresponding values for females. The $ICW_{diff}$ values for males were also significantly greater ($P < 0.001$) than were the corresponding values for females. Although the mean $ECW_{diff}$ values for males and females were not statistically different from zero, the mean values were statistically different ($P < 0.001$) between the gender groups. The scatter in the individual values for $ICW_{diff}$ (see Fig. 2) and $TBW_{diff}$ (see Fig. 3) was not independent of the average values, whereas the individual data for $ECW_{diff}$ (see Fig. 1) were unrelated to the corresponding average values, although the scatter was large. The ±2 SD lines in each of the figures correspond to the limits of agreement as defined by Bland and Altman (5).

The population of children and young adults in the present study represented a wide range of weights, heights, and body sizes. This is reflected by the large SD values for each of the variables reported in Table 1. Likewise, the large SD values for the $V_{ECF}$, $V_{ICF}$, and $V_{TBW}$ values can be attributable to the population selection. Some of the spread in the $TBW_{diff}$, $ECW_{diff}$, and $ICW_{diff}$ values may also be due, in part, to this same reason. Therefore, to provide a more meaningful comparison with the findings recently reported by De Lorenzo et al. (8) for healthy young men, we have selected two subgroups from the male population in the present study. The first subgroup (group A) consisted of all men above 16 yr of age, with height in the same range (165–185 cm) as that reported by De Lorenzo et al. The second subgroup (group B) consisted of 14 individuals from within group A who were also weight matched on the basis of their body mass index (Wt/Ht$^2$) with individuals in the De Lorenzo study. The mean ± SD values for the De Lorenzo et al. group and for groups A and B are given in Table 3. The mean $TBW$ values among the three groups of men were not statistically different. The mean $ECW$ values, however, were statistically different ($P < 0.01$), with those for the present study being higher, on average, by ~1.1 liter. This, in turn, forced the calculated values for $ICW$ for groups A and B to be lower by similar volumes. The mean values

Fig. 1. Relationship between difference value for extracellular water ($ECW_{diff}$) and average ECW, where $ECW_{diff} = V_{ECF} - ECW$ and average ECW = ($V_{ECF} + ECW$)/2. ±2 SD lines, limits of agreement between methods [Bland-Altman test (5)].

Fig. 2. Relationship between difference value for intracellular water ($ICW_{diff}$) and average ICW, where $ICW_{diff} = V_{ICF} - ICW$ and average ICW = ($V_{ICF} + ICW$)/2. ±2 SD lines and symbols are defined as in Fig. 1.

Fig. 3. Relationship between difference value for total body water ($TBW_{diff}$) and average TBW, where $TBW_{diff} = V_{TBW} - TBW$ and average TBW = ($V_{TBW} + TBW$)/2. ±2 SD lines and symbols are defined as in Fig. 1.
for ECF and ICF resistance values ($R_{ECF}$ and $R_{ICF}$) were higher in groups A and B than were those observed by De Lorenzo et al., whereas the values for $V_{TBW}$, $V_{ECF}$, and $V_{ICF}$ were not appreciably different. It is noteworthy that the range of values for ECW in height-matched (group A) subjects was about twice that reported by De Lorenzo et al. When the subjects were also matched for body mass index (group B), the range of ECW values was reduced when compared with group A, but it was still considerably greater than that reported by De Lorenzo et al.

The mathematical relationships given in Eqs. 4 and 5 provide the associations among the measured anthropometric parameters (height, weight), the calculated electrical parameters ($R_v$ and $R_i$), and the theoretical values for $V_{ECF}$ and $V_{ICF}$. We can rearrange the terms in Eqs. 4 and 5 to solve for the constants, denoted by $k_{ECF}$ and $k_v$, with the dilution values for ECW and ICW substituted for the BIS estimates. On the basis of this approach and the data of De Lorenzo et al. (8), we calculated that the mean values for the $k_{ECF}$ and $k_v$ constants were 0.307 and 3.515, respectively. For the men in our group A, we obtained mean values of 0.339 for $k_{ECF}$ and 3.234 for $k_v$. For the men in group B, the constants were very similar: 0.348 for $k_{ECF}$ and 3.264 for $k_v$. In the total population in the present study, we obtained mean values of 0.370 for males and 0.358 for females for $k_{ECF}$. The corresponding mean values for $k_v$ were 3.032 for males and 2.694 for females.

**DISCUSSION**

The BIS measurement has many practical advantages when compared with the dilution method, especially for the individual being examined. It does not require the subject to drink an extremely salty solution, to incur the discomfort or risk associated with the collection of several blood samples, or to remain fasting and available for 3–4 h during the equilibration period. In addition, the BIS instrumentation is relatively inexpensive and requires low maintenance and minimal operator training, and the measurements can be repeated as frequently as needed. A further benefit for the clinical setting is that the results are immediately available. These general characteristics clearly support BIS as the better choice in terms of the practical aspects of the measurement of body fluid volumes, especially when these measurements are to be obtained in children. Although a number of studies have reported the use of the single-frequency BIA measurement in children (13, 24), relatively few studies have used the BIS technique in this population (2, 3, 22). The present study, therefore, may provide the first direct comparison of BIS with the classic dilution methods for a large population of healthy children, adolescents, and young adults of both genders and of varying ethnicity. The age range examined in this study was chosen to ensure a wide variation in body size, shape, and composition. This variation was selected to adequately test the basic assumptions associated with the Hanai model (12) used in the BIS methodology.

In the present study, all three body water compartment estimates obtained by using BIS were highly correlated with the corresponding values for the dilution techniques. However, the regression lines for all three relationships did not match the line of identity (slope = 1, intercept = 0) when the values for the constants $k_{ECF}$ and $k_v$, provided with the BIS instrument, were used. Because our study provides a comparison of two methods (dilution vs. BIS), it would not be appropriate to attribute all of the differences solely to one technique. For the dilution technique, questions may be raised with regard to the choice of tracer, the most appropriate body fluid to assay, and the point at which equilibration of the tracer is reached (20, 26).

However, for the measurement of TBW, numerous studies have clearly shown that equilibration is reached in the plasma by at least 2 h after an orally administered dose of labeled water (20). Thus in our study it was very reasonable to assume that the oral $^2$H$_2$O dose had reached equilibration by the time the second plasma sample was collected. Also, plasma was assayed, eliminating any questions related to the selection of body fluid. Furthermore, because our subjects restricted their fluid intake and refrained from voiding during this period, it is unlikely that there was any significant over- or underexpansion of the TBW compart-

### Table 3. Comparison with findings reported by De Lorenzo et al. (8)

<table>
<thead>
<tr>
<th></th>
<th>Wt, kg</th>
<th>Ht, cm</th>
<th>BMI, kg/m$^2$</th>
<th>TBW, liters</th>
<th>ECW, liters</th>
<th>ICW, liters</th>
<th>$R_{ECF}$, k$^2$</th>
<th>$R_{ICF}$, k$^2$</th>
<th>$V_{TBW}$, liters</th>
<th>$V_{ECF}$, liters</th>
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<tr>
<td>De Lorenzo et al. (Ref. 8; n = 14 men)*</td>
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<td></td>
<td>74.8 ± 9.2</td>
<td>175.3 ± 6.7</td>
<td>24.3 ± 2.2</td>
<td>45.5 ± 4.0</td>
<td>18.3 ± 2.1</td>
<td>27.1 ± 2.7</td>
<td>577.7 ± 46.6</td>
<td>1,020.4 ± 84.4</td>
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<td>21.0 ± 2.0</td>
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<tr>
<td>%CV</td>
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<td>3.9%</td>
<td>8.8%</td>
<td>8.8%</td>
<td>11.5%</td>
<td>10.1%</td>
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<td>8.3%</td>
<td>9.4%</td>
<td>9.6%</td>
<td>11.7%</td>
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<td>Group A in present study (n = 73 men)†</td>
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<td></td>
<td>73.5 ± 12.8</td>
<td>175.7 ± 5.1</td>
<td>23.8 ± 4.0</td>
<td>44.3 ± 7.1</td>
<td>19.1 ± 4.3</td>
<td>25.4 ± 5.1</td>
<td>630.8 ± 86.5</td>
<td>1,068.6 ± 212.0</td>
<td>39.8 ± 6.2</td>
<td>20.0 ± 3.0</td>
<td>19.9 ± 3.9</td>
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<tr>
<td>%CV</td>
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<td>22.7%</td>
<td>20.2%</td>
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<td>Group B in present study (n = 14 men)‡</td>
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<td></td>
<td>73.7 ± 7.6</td>
<td>176.0 ± 6.1</td>
<td>23.8 ± 1.8</td>
<td>45.0 ± 3.8</td>
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<td>16.6%</td>
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<td>8.7%</td>
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Values are means ± SD; n, no. of subjects. BMI, body mass index. Dilution measurements were made of TBW, ECW, and ICW. BIS measurements were made of resistance values for extracellular fluid and intracellular fluid ($R_{ECF}$ and $R_{ICF}$, respectively), $V_{TBW}$, $V_{ECF}$, and $V_{ICF}$. *Men only, age 21–57 yr, height 167–185 cm [De Lorenzo et al. (8); J. Matthie, personal communication, 1997]. †Men only, age 16–29 yr, height 165–185 cm. ‡Men matched for height and BMI (kg/m$^2$) with subjects examined by De Lorenzo et al. (8).
BODY WATER MEASUREMENTS

Although there may be some uncertainty as to what value to use for the constant to account for the incorporation of the tracer into the nonaqueous tissues, this choice has been shown to alter the TBW estimates by <0.5% (20). For the BIS measurement, total body water (VTBW) was obtained as the sum of the extracellular (VECWF) and intracellular (VICWF) values. Thus the differences seen in Fig. 3 may reflect a bias associated with either or both of these BIS estimates.

For the ECW compartment, the Br-dilution and BIS methods produced comparable mean results (see Fig. 1 and Table 2) for males and females. The second criterion for interchangeability between methods (8), however, was not met for females because the individual ECWdiff values were not independent of the average values. Furthermore, a considerable number of males and females had ECWdiff values outside the ±2 SD limits. As we have already noted, when two methods are compared, it is usually not statistically appropriate to attribute all of these differences solely to one method. For the Br-dilution measurement of ECW, several different radioactive and stable tracers have been used, different body fluids have been sampled, and time to allow for equilibration of the tracer has varied among investigators (6, 20, 22, 26). However, ECW estimates based on Br dilution at 3–4 h have been shown to be in good agreement with those obtained by the direct measurement of total body chlorine (31). Furthermore, although no official consensus has been reached for standardization of the Br-dilution method, the most commonly reported procedure (as used in this study) has been to assay a plasma sample collected at 3–4 h after an oral Br dose (7, 9, 20, 30, 31).

For the BIS estimates for VECWF, based on the Hanai model (12), to be successful, the term kECWF in Eq. 4 must be constant. For this model to be applicable to a pediatric population, the value for kECWF must be relatively invariant to changes in body composition with age and during growth. In the initial studies of adults by Van Loan et al. (25), the values for kECWF and kECWF were reported as 0.306 and 3.82 for males and 0.316 and 3.40 for females, respectively. For the 14 young adult men examined by De Lorenzo et al. (8), values used for the kECWF and kECWF constants were 0.307 and 3.498, respectively. Armstrong et al. (1) used values of 0.337 and 2.905 for the kECWF and kECWF constants, respectively, when they examined the relationship between the BIS and dilution methods in 13 healthy young men. Gudividika et al. (11) used similar values (kECWF = 0.338, and kECWF = 2.968) when they examined the effects of skin temperature on multifrequency measurements in six healthy adults. Van Marken Lichtenbelt et al. (27) examined 10 healthy adults, and, on the basis of the specific resistivity values reported, we calculated the mean kECWF values to be 0.245 for males and 0.238 for females. The corresponding values for kECWF appear to be 6.408 for males and 6.469 for females. Only Smye et al. (22) have reported BIS measurements for VECWF in children. When they compared the body’s clearance of 99mTc-labeled diethylene triamine pentaacetate with the results for the BIS measurement, the mean value calculated for kECWF was 0.335. In the present study, we obtained mean values for kECWF of 0.370 for the total male population and 0.358 for the female population. Unfortunately, we did not find either of these values to be constants because their %CVs were 19.1%. Similarly, when we calculated the mean values for kECWF, as 3.032 for males and 2.694 for females, the corresponding %CVs were 25-28%. To be considered as constants in terms of body composition parameters, one would expect the %CVs to be <5% (28). Although substitution of our recalculated gender-specific mean values for kECWF and kECWF produced new values for VECWF, VICWF, and VTBW, such that the mean biases (ECWdiff, ICWdiff, and TBWdiff) relative to the dilution volumes were virtually zero, the wide range in individual differences was not significantly altered.

There are three parameters (Kb, Db, pECWF) that are used to derive the value for kECWF. Although any one of these three parameters need not be constant over the age range examined in the present study, their product as defined by the equation for kECWF must remain relatively constant for use with the Hanai model (8). Furthermore, the nature of the mathematical relationship among these three parameters within the equation for kECWF shows that any one of the three can serve as a scalar for the determination of the VECWF values. That is, with two of the values held constant, the third value can be adjusted such that the average bias (ECWdiff) for the VECWF will become zero. It is important, however, to appreciate that although the average bias can be forced to zero, this will not appreciably reduce the range for the individual ECWdiff values. Therefore, to reduce the differences between the dilution and BIS estimates, it appears that the kECWF term may not be constant among individuals for the full age range examined in this study. One possibility is that the tissue resistivity values (pECWF, pICWF) used to calculate kECWF and kECWF are not constant for all ages. Alternately, Kb may need to be adjusted for age and gender (19, 23), especially during periods of rapid growth. Although the third possibility is that Db for children needs to be changed with age (10), its relative impact on the kECWF value is much less than that for either Kb or pECWF. Also, because Kb is not used in the VICWF equation, the most logical choice is to alter the pECWF value. It appears that agreement between the BIS and dilution methods for adults has been best achieved when tissue resistivity values have been recalculated for each specific population (1, 2, 8, 14, 22, 27). That is, the BIS instrument can easily be recalibrated on a group basis to achieve approximately zero mean differences between the VECWF and VICWF or VTBW estimates when compared with dilution-based values. This, however, does not necessarily ensure that the BIS estimates are accurate for any subsequent studies in a different population or even for individuals within the original calibration population. For multifrequency bioelectrical impedance methods to be universally applicable, the models and basic assumptions used to describe the body’s water distributions, including any inferred constants, should be independent of the population from which they were derived. In the present study, the %CVs for the recalculated kECWF...
and $k$, terms were too large (19–29%) to consider these parameters as constants within the context of body composition analysis (28). It remains unknown how much of this lack of agreement between the dilution methods and the BIS measurement can be attribute solely to the latter technique.

We acknowledge the contributions of R. J. Shyapalo and J. J. Posada for the bioelectrical impedance spectroscopy measurements, J. A. Pratt for the Br-dilution assay, L. L. Clarke and S. Zhang for the $^{2}$H$_{2}$O-dilution assay, and L. Loddeke for editorial assistance with preparation of the manuscript.

This work is supported by the US Department of Agriculture, Agricultural Research Service (USDA/ARS), under Cooperative Agreement no. 58-6250-6-001 with the Baylor College of Medicine.

This work is a publication of the USDA/ARS Children’s Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, and Texas Children’s Hospital, Houston, TX. The contents of this publication do not necessarily reflect the views or policies of the USDA, nor does mention of trade names, commercial products, or organizations imply endorsement.

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Received 12 December 1997; accepted in final form 13 May 1998.

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