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Body Composition Evaluation in Peritoneal Dialysis Patients Using Anthropometric Formulas Estimating Body Water

In adult patients on peritoneal dialysis (PD), estimates of body water (V), fat-free mass (FFM), and body fat (BF) can be obtained by using anthropometric formulas for estimating V. Estimates of V, FFM, and BF can also be obtained by using reference (standard) methods in which V is evaluated by a standard dilution method. To test whether the estimates obtained by the various methods agree, we analyzed published studies that measured V by a standard method in adult PD patients. We then calculated V, FFM, and BF by the Watson, Hume, Sahlgrenska, Chumlea, Lee, and Chertow formulas for the “average subject” in the published studies. We compared the standard and the anthropometric estimates using the limits-of-agreement method of Bland and Altman. Our analysis included six studies involving a total of 262 patients (89 women, 173 men). The six studies measured V by a reference method and allowed calculation of anthropometric V, FFM, and BF for the average patient.

We calculated these values: V

| Standard | 36.8 ± 4.7 L; V      |
| Sahlgrenska | 36.9 ± 4.3 L [p = nonsignificant (NS)]; Bland–Altman limits of agreement: −3.1 L to 3.3 L]; FFM Standard: 50.9 ± 5.2 kg; FFM Sahlgrenska: 50.6 ± 4.3 kg (Bland–Altman limits of agreement: −5.4 kg to 4.8 kg); BF Standard: 20.3 ± 3.0 kg; BF Sahlgrenska: 20.6 ± 2.3 kg (Bland–Altman limits of agreement: −4.8 kg to 5.4 kg).

Results obtained using the Watson, Hume, Chumlea, and Lee formulas also agreed with the standard estimates. The Chertow formula produced results that systematically overestimated the standard V and FFM values and that underestimated the standard BF.

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Key words
Body composition, body water, fat-free mass, body fat, obesity, hydration

Introduction
Monitoring body composition is an important part of nutrition evaluation in peritoneal dialysis (PD) patients. The body water (V) content of individuals provides information about their degree of fatness (1). Estimates of V—including those arrived at using anthropometric formulas—have been used to provide quantitative estimates of body fat (BF) and fat-free mass (FFM) in studies on PD patients (2). However, anthropometric estimates of body composition may be unreliable in some instances (2).

The purpose of the present study was to assess the accuracy of anthropometric estimates of body composition in PD patients. To that end, we calculated anthropometric estimates of V, FFM, and BF for the patients from several published studies that measured body water in PD patients by reference methods. We then compared the results with the estimates of V, FFM, and BF by the reference methods.

Patients and methods
Analyses of body composition using anthropometric formulas that estimate V are based on two assumptions: (A) All the water in the body is localized to the
fat-free mass. (B) The water content of fat-free mass is constant at 0.73 L/kg. In that case, FFM = V / 0.73 and BF = W – (V / 0.73) (2). In subjects with hydration disorders, defined as V / FFM > 0.73, anthropometric estimates of FFM and BF are, by definition, inaccurate.

We used anthropometric equations that compute body composition from V values to estimate the body composition of PD patients. We then compared those estimates to estimates obtained by standard methods in studies that reported values of V, FFM, and BF obtained by using reference (standard) methods in PD patients. The indispensable inclusion criterion was measurement of body water by a standard method. Studies were excluded if they lacked the data needed for calculation of body composition by the anthropometric formulas or if they estimated V by bioelectrical impedance analysis (BIA) rather than by a tracer dilution method (because of reported discrepancies between BIA estimates of V and standard measurements).

We identified six studies that provided estimates of V by standard methods in adult PD patients (3–8). Five of the studies also provided estimates of FFM and BF that were obtained using independent reference methods. Arkouche et al. (3) measured V by stable H<sup>18</sup>O isotopic measurement and BF by skinfold thickness. In a study by de Fijter et al. (4), V was measured by antipyrine dilution, and BF, by skinfold thickness. Woodrow et al. (5) estimated V by <sup>2</sup>H<sub>2</sub>O dilution and FFM by dual-energy X-ray absorptiometry (DEXA). Dahl et al. (6) estimated V by ethanol dilution. In a study by Johansson et al. (7), V was measured by <sup>3</sup>H<sub>2</sub>O dilution, and FFM, by quantitation of total body potassium. Finally, Konings et al. (8) measured V by <sup>3</sup>H<sub>2</sub>O dilution and FFM by DEXA.

For the average subject in each of the six studies, we estimated anthropometric V, FFM, and BF using the Watson (9), Hume (10), Sahlgrenska (8), Chumlea (11), Chertow (12), and Lee (13) anthropometric formulas. For all studies except one (6), we used the Chumlea formulas for white subjects only. For the study by Dahl et al. (6), because of the large number of African-American patients with renal failure in New Jersey, we calculated V first using the Chumlea formulas for Caucasians and then using the Chumlea formulas for African Americans, and then we averaged the calculated values of V. Estimates of V, FFM, and BF by the Chertow formula were made assuming that no subject had diabetes mellitus.

Continuous variables are reported as mean ± standard deviation. We used the two-tailed paired t-test to compare each estimate by an anthropometric method to the corresponding standard estimate—for example, estimate of FFM by the Watson formula compared with the standard method—and we used the method of Bland and Altman (14) to calculate the limits of agreement. To account for the differences in the number of subjects studied in each report, we also calculated mean values weighted for the number of individuals in each study. That fractional error, calculated as (anthropometric estimate – standard estimate) / (standard estimate) × 100 (15), was used to compare the weighted mean values.

**Results**

The six studies we analyzed contained between 8 (3) and 165 (7) patients. The total number of subjects was 262 (89 women and 173 men). Anthropometric measurements were age (58.4 ± 5.6 years; weighted mean: 57.7 years), height (167.4 ± 7.0 cm; weighted mean: 170.3 cm), weight (71.2 ± 6.1 kg; weighted mean: 72.0 kg), and body mass index [(BMI) 25.4 ± 1.2; weighted mean: 24.8].

Table I shows the mean estimates of V, FFM, and BF arrived at using the standard methods and the anthropometric formulas. The anthropometric estimates of V, FFM, and BF using the Watson, Hume, Sahlgrenska, Chumlea, and Lee formulas did not vary from the corresponding estimates obtained using the standard methods (two-tailed paired t-test). The estimates of V and FFM by the Chertow formula exceeded the corresponding estimates obtained using the standard methods (p < 0.005), and the estimates of BF

<table>
<thead>
<tr>
<th>Formula</th>
<th>V (L)</th>
<th>FFM (kg)</th>
<th>BF (kg)</th>
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<tbody>
<tr>
<td>Standard</td>
<td>36.8 ± 4.7</td>
<td>50.9 ± 5.2</td>
<td>20.3 ± 3.0</td>
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<tr>
<td>Watson</td>
<td>36.5 ± 4.0</td>
<td>50.2 ± 5.5</td>
<td>21.0 ± 2.2</td>
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<tr>
<td>Hume</td>
<td>37.9 ± 4.1</td>
<td>51.9 ± 5.7</td>
<td>19.3 ± 2.1</td>
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<tr>
<td>Sahlgrenska</td>
<td>36.9 ± 4.3</td>
<td>50.6 ± 5.9</td>
<td>20.6 ± 2.3</td>
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<tr>
<td>Chumlea</td>
<td>38.2 ± 4.8</td>
<td>52.1 ± 6.6</td>
<td>19.1 ± 2.2</td>
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<tr>
<td>Lee</td>
<td>36.6 ± 4.5</td>
<td>50.4 ± 6.2</td>
<td>21.1 ± 2.1</td>
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<tr>
<td>Chertow</td>
<td>40.0 ± 4.7</td>
<td>54.8 ± 6.4</td>
<td>16.4 ± 2.3</td>
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derived using the standard methods exceeded the corresponding Chertow estimates ($p < 0.01$).

Table II shows the Bland–Altman estimates of the limits of agreement ($d \pm 2ds$, where $d$ is the difference between the anthropometric estimate and the standard estimate, and $ds$ is the standard deviation of the differences) between the anthropometric and the standard estimates. The entire 95% confidence interval of the differences between $V$ estimated from the Chertow formula and the standard $V$ was above zero. For all other comparisons, the 95% confidence interval of the differences overlapped zero.

Table II also shows the fractional errors of the weighted means of the anthropometric estimates of $V$, FFM, and BF, assuming that the values obtained using the reference dilution methods are the “gold standard.” The weighted means of the estimates of $V$ obtained using the Watson, Hume, Sahlgrenska, Chumlea, and Lee formulas differed from the weighted mean of the standard estimate by $<5\%$. The weighted mean of the Chertow estimate of $V$ exceeded the corresponding weighted mean of the standard estimates by $>10\%$. The weighted means of estimates of FFM derived using the other five formulas differed from the weighted mean of the standard estimate of FFM by $<3\%$. The weighted mean of the estimate of FFM by the Chertow formula exceeded the weighted mean of the corresponding value by the standard method by 7.9%. The weighted means of estimates of BF by the other five formulas differed from the weighted mean of the standard estimate of BF by $<8\%$. The weighted mean estimate of BF by the Chertow formula was 22% below the weighted mean of the corresponding standard estimate.

**Discussion**

For a long time, estimates of body water have been recognized as one way of evaluating body composition (16). The underlying principles of that evaluation—that body fat contains no water and that the water content of lean body mass is constant—are applied in the evaluation of body composition by several methods [for example, DEXA (8)]. Estimates of $V$ by anthropometric formulas provide an inexpensive and convenient method for evaluating body composition, and such formulas have been applied in studies of PD patients (2).

The present study has two main findings: (A) The use of the Hume, Watson, Sahlgrenska, Chumlea, and Lee formulas to estimate $V$, FFM, and BF for PD patients with average body composition was not associated with any systematic errors. (B) The limits of

<table>
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<th>A. Bland–Altman calculations of limits of agreement with the standard method</th>
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<td>Watson</td>
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<td>Chertow</td>
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<th>B. Weighted means and their fractional errors</th>
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<td><strong>Formula</strong></td>
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*Weighted means for standard estimates were $V = 37.9 L$, FFM = 52.9 kg, BF = 19.1 kg.

$V =$ body water; FFM = fat-free mass; BF = body fat; $d =$ mean difference between the anthropometric and the standard estimate; $ds =$ standard deviation of the differences; Fr. = fractional.
agreement between the anthropometric and reference estimates of body composition for the average patient in separate six studies were narrow. The agreement between the estimates by all five formulas and by the reference methods was remarkable because the formulas were developed in different populations, and the reference methods for evaluating body composition varied among the studies analyzed.

Patients on PD with a body composition close to the average can be analyzed using one of the five anthropometric formulas. However, if the body composition of a PD patient differs substantially from the average, the same formulas may produce substantial errors—particularly in patients who are obese or overhydrated. Estimates of $V$ by anthropometric formulas with a linear regression coefficient for weight (all formulas except the Chertow formula) systematically overestimate body water and FFM, and underestimate BF in obese PD patients (2,7,8). The errors are compounded in the subset of PD patients who lose lean body mass as they develop obesity (17–19). In overhydrated PD patients, anthropometric formulas (with the exception of the Chertow formula) underestimate $V$ (17), but overestimate both FFM and BF, as illustrated by this hypothetical example: In a 50-year-old male PD patient with a height of 170 cm and a dry weight of 70 kg, $V$ is 39.8 L, FFM is 54.5 kg, and BF is 15.5 kg by the Sahlgrenska formula. If the man were to gain 10 L of fluid, his body water would be 49.8 L, but his FFM and BF would remain at 54.5 kg and 15.5 kg respectively. However, in that case, the Sahlgrenska formula would calculate a $V$ of 42.9 L, an FFM of 58.8 kg, and a BF of 21.1 kg.

**Conclusion**

The use of anthropometric formulas to estimate body composition in PD patients who are obese or overhydrated may lead to large errors. However, in PD subjects with average or close-to-average body composition, the Hume, Watson, Sahlgrenska, Chumlea, and Lee formulas provide estimates of body composition that approximate, with relatively narrow margins of error, the estimates provided by reference methods.

**Acknowledgment**

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**Appendix: Anthropometric formulas for estimating body water**

**Symbols**

$V$ = body water (L); $H$ = height (cm); $W$ = actual weight (kg); $A$ = age (years); BMI = body mass index; $G$ = sex (males = 1, females = 0); $D$ = diabetes (yes = 1; no = 0).

**The Watson formulas (9)**

Men: $V = 2.447 + 0.1074H + 0.3362W - 0.0951A$

Women: $V = -2.097 + 0.1069H + 0.2466W$

**The Hume formulas (10)**

Men: $V = -14.012934 + 0.194786H + 0.2962W$

Women: $V = -35.270121 + 0.344547H + 0.1838W$

**The Sahlgrenska formulas (8)**

Men: $V = -10.759 + 0.192H + 0.312W - 0.078A$

Women: $V = -29.994 + 0.294H + 0.214W - 0.0004A$

**The Chumlea formulas (11)**

White men: $V = 23.04 + 0.50W - 0.03A - 0.62BMI$

Black men: $V = -18.37 + 0.25H + 0.34W - 0.09A$

White women: $V = -10.50 + 0.18H + 0.20W - 0.01A$

Black women: $V = -16.71 + 0.24H + 0.22W - 0.05A$

**The Lee formulas (13)**

Men: $V = -28.3497 + 0.243057H + 0.366248W$

Women: $V = -26.6224 + 0.262513H + 0.232948W$

**The Chertow formula (12)**

$V = -0.07493713A - 1.01767992G + 0.12703384H - 0.04012056W + 0.57894981D - 0.00067247W^2 - 0.03486146AG + 0.11262857GW + 0.00104135AW + 0.00186104HW$

**References**

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