Comparison of anthropometric equations for estimation of total body water in peritoneal dialysis patients

Graham Woodrow¹, Brian Oldroyd², Antony Wright³, W. Andrew Coward³, John G. Truscott², John H. Turney¹, Aleck M. Brownjohn¹ and Michael A. Smith⁴

¹Renal Unit, Leeds General Infirmary, Leeds, ²Centre for Bone and Body Composition Research, University of Leeds, Leeds, ³MRC—Human Nutrition Research, Cambridge and ⁴Academic Unit of Medical Physics, University of Leeds, Leeds, UK

Abstract

Background. Several formulae exist for estimating total body water (TBW). We aimed to assess their validity in peritoneal dialysis patients by comparison with TBW estimated by deuterium oxide dilution (TBW_D).

Methods. We compared the equations of Chertow (TBW_Cher), Chumlea (TBW_Chum), Hume and Weyers (TBW_HW), Johansson (TBW_J), Lee (TBW_L), Watson (TBW_W) and TBW as 58% of body weight (TBW0.58Wt) with TBW_D in 31 peritoneal dialysis (PD) patients and 32 controls. Estimates were compared with TBW_D using Bland and Altman comparison. Extracellular water (ECW) was also estimated by sodium bromide dilution.

Results. In PD patients, mean TBW_D was 35.04 (SD 7.84) l. Estimates were greater for TBW_Cher, TBW_Chum, TBW_HW, TBW_J and TBW0.58Wt. Mean TBW_L and TBW_W did not differ from TBW_D. Ninety-five percent limits of agreement (LOA) compared with TBW_D (as a percentage of the mean) were similar for all of the different equations in PD patients (between ±15.4 and ±17.3%) except TBW0.58Wt, which was far greater (±26.4%). In controls, mean TBW_D was 37.03 (SD 6.63) l. Estimates were greater for TBW_Cher, TBW_Chum, TBW_HW, TBW_J and TBW0.58Wt. Mean TBW_L and TBW_W did not differ from TBW_D. Ninety-five percent LOA compared with TBW_D (as a percentage of the mean) were similar for all equations in the controls, and closer than in PD patients (between ±9.1 and ±11.5%) except TBW0.58Wt, which was again far greater than the other equations (±28.1%).

TBW_HW – TBW_D correlated with mean TBW (r = −0.412, P < 0.05 in PD and r = −0.383, P < 0.05 in controls). TBW_W – TBW_D (r = −0.539, P < 0.005) correlated with mean TBW in PD. TBW0.58Wt – TBW_D correlated with body mass index (BMI) (r = 0.624, P < 0.0001 in PD and r = 0.829, P < 0.0001 in controls) and ECW/TBW (r = 0.406, P < 0.05 in PD and r = 0.411, P < 0.02 in controls).

Conclusions. Predictive equations were less accurate in PD than controls. TBW0.58Wt was most inaccurate, with systematic overestimation of TBW with increasing BMI and ECW/TBW. There were no differences in LOA with TBW_D for the other equations within each group.

Keywords: anthropometric equations; body composition; dialysis adequacy; peritoneal dialysis; total body water

Introduction

Water represents the dominant chemical component of the body. Estimation of the volume of total body water (TBW) in patients with advanced chronic renal failure (CRF) is of great importance in expressing measurement of dialytic and residual renal urea clearance. Clearance of urea is expressed as Kt/V (urea), where urea clearance in unit time (Kt) is normalised to the estimated volume of TBW, which is equivalent to the volume of distribution of urea in the body (V). In patients on peritoneal dialysis (PD), or non-dialysis patients with advanced CRF, the volume V needs to be estimated independently of clearance measurements. This is usually performed indirectly from anthropometric equations based on body weight, and variably terms such as height, gender and age. These methods are all limited in that they do not measure TBW directly. They depend on general assumptions about uniformity of body composition and body water content, which actually vary between individual subjects, even in healthy individuals, but particularly in...
Equations for estimation of total body water in peritoneal dialysis

patients with diseases such as renal failure, which lead to loss of normal regulation of TBW content.

The most commonly used equations for estimating TBW for calculation of Kt/V are those of Watson et al. [1] and sometimes Hume and Weyers [2]. Most crudely, TBW may be estimated as a fixed proportion of body weight (e.g. 58% of body weight). Because of the substantial potential inaccuracies seen in individual subjects with these methods, newer predictive equations derived in varying contemporary subject groups comprising healthy [3] and CRF patients [4–6] have been developed. The aims of this study were to evaluate these varying predictive equations in a group of patients on PD and a group of healthy control by comparison with TBW measured by deuterium oxide dilution (TBWD).

Subjects and methods

We studied 31 patients on chronic PD (27 CAPD and four APD) and 32 healthy control subjects. PD patients were free of clinical signs of significant fluid overload, were clinically stable and free of recent acute illnesses and had been receiving PD for a minimum of 3 months. Subject characteristics, including body water volumes estimated by dilution techniques are shown in Table 1, with no significant differences between patient and control groups. Most subjects were of Caucasian origin, apart from two Afro-Caribbean subjects and one South Asian subject in the PD group and one Afro-Caribbean control subject.

TBW was measured by deuterium oxide dilution (TBWD). Subjects ingested a dose of 1 g/kg body weight of 7% deuterium oxide (2H2O) solution in water. The isotopic ratio 2H/1H of deuterium was detected in saliva prior to the dose (baseline sample), and at 4, 5 and 6 h post-dose by isotope mass spectrometry. TBW was determined by the dilution principle, using the mean of the baseline-corrected enrichment values at 4–6 h. The 2H2O dilution space thus obtained was divided by a factor of 1.04 to account for the exchange of 2H with non-aqueous hydrogen. The coefficient of variation for the post-dose saliva deuterium concentrations and hence TBW determined from their means was <1%.

Extracellular water (ECW) was estimated by bromide dilution. Patients ingested a dose of 1.55 g/kg body weight of 3.22% sodium bromide solution (25 mmol Br−/ml of solution). Bromide was measured in plasma pre-dose and at 4 and 6 h post-dose. ECW was calculated by assuming complete equilibration of bromide throughout the extracellular space and the derived value corrected by factors for the concentration of water in plasma (0.94), Gibbs–Donnan effect (0.95) and intracellular concentration of bromide (0.90).

TBW was estimated by the anthropometric equations of Chertow et al. [5] (TBWCher), Chumlea et al. [3] (TBWChum), Hume and Weyers [2] (TBWHW), Johansson et al. [4] (TBWL), Lee et al. [6] (TBWl), Watson et al. [1] (TBWw) and as 58% of body weight (TBW0.58Wt). Full details of the equations are given in the Appendix.

Differences of means between groups were calculated by paired or unpaired t-tests as appropriate, relationships between variables by the Pearson correlation coefficient and comparison of measurement techniques by the Bland and Altman method [7].

The study was approved by the local research ethics committee and all subjects gave written consent to participate in the study.

Results

TBWD dilution did not significantly differ between the PD and control groups (Table 1). Mean values of estimated TBW were compared with TBWD for the two groups (Table 2). Mean values of estimated TBW were greater than TBWD for TBWCher, TBWChum, TBWHW, TBWL, TBWJ and TBW0.58Wt for both the PD

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**Table 1.** Patient and control subject characteristics

<table>
<thead>
<tr>
<th></th>
<th>PD patients</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (male/female)</td>
<td>31/15</td>
<td>32/17</td>
</tr>
<tr>
<td>Gender (years)</td>
<td>53.68 (13.16)</td>
<td>51.33 (10.26)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167.63 (10.78)</td>
<td>168.31 (8.30)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>69.41 (11.16)</td>
<td>74.71 (13.71)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.73 (3.58)</td>
<td>26.33 (4.36)</td>
</tr>
<tr>
<td>TBW (l)</td>
<td>35.04 (7.84)</td>
<td>37.03 (6.63)</td>
</tr>
<tr>
<td>ECW by bromide dilution (l)</td>
<td>17.58 (3.56)</td>
<td>17.45 (3.24)</td>
</tr>
<tr>
<td>ECW/TBW</td>
<td>0.51 (0.07)</td>
<td>0.48 (0.07)</td>
</tr>
<tr>
<td>TBW/weight (%)</td>
<td>50.41 (7.52)</td>
<td>50.15 (6.80)</td>
</tr>
</tbody>
</table>

Values expressed as mean (SD). There were no significant differences compared with independent sample t-test.

**Table 2.** TBW as absolute volume and percent body weight estimated by anthropometric equations compared with TBWD

<table>
<thead>
<tr>
<th></th>
<th>PD patients</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBW (l)</td>
<td>35.04 (7.84)</td>
<td>37.03 (6.63)</td>
</tr>
<tr>
<td>TBW/weight (%)</td>
<td>50.41 (7.52)</td>
<td>50.15 (6.80)</td>
</tr>
<tr>
<td>TBWCher</td>
<td>39.61 (7.25), ( P &lt; 0.0001 )</td>
<td>40.80 (6.80), ( P &lt; 0.0001 )</td>
</tr>
<tr>
<td>TBWChum</td>
<td>37.01 (7.43), ( P = 0.001 )</td>
<td>38.18 (6.78), ( P &lt; 0.01 )</td>
</tr>
<tr>
<td>TBWw1</td>
<td>36.85 (6.60), ( P &lt; 0.005 )</td>
<td>38.33 (5.90), ( P &lt; 0.005 )</td>
</tr>
<tr>
<td>TBWw</td>
<td>36.22 (6.82), ( P &lt; 0.05 )</td>
<td>37.80 (6.29), ( P &lt; 0.05 )</td>
</tr>
<tr>
<td>TBWl</td>
<td>35.89 (7.04)</td>
<td>37.34 (6.66)</td>
</tr>
<tr>
<td>TBWw</td>
<td>35.91 (6.18)</td>
<td>37.33 (6.10)</td>
</tr>
<tr>
<td>TBW0.58Wt</td>
<td>40.26 (6.47), ( P &lt; 0.0001 )</td>
<td>43.33 (7.95), ( P &lt; 0.0001 )</td>
</tr>
</tbody>
</table>

Mean values compared by paired t-test.
and the control groups. Means of TBW_L and TBW_W did not differ from TBW_D.

Bland and Altman comparisons of estimated TBW values with TBW_D are shown in Table 3. Mean intermethod differences show particularly large bias for TBW Cher and TBW_0.58Wt, overestimating TBW compared with TBW_D. The magnitude of the ranges of the 95% limits of intermethod agreements were much larger within each study group for TBW_0.58Wt than the other equations, which were very similar. The ranges of the 95% limits of intermethod agreements were greater in the PD group than in the control group.

The two study groups were also analysed as subgroups split by gender (data not reported in detail). Similar results were seen for comparisons of mean estimated TBW by most equations with TBW_D. TBW_0.58Wt produced a far greater overestimate of TBW_D in male than male subjects. TBW Cher was clearly greater than TBW_D for both PD and controls in males. In females, the difference did not reach statistical significance in PD and in female controls the two means were identical. The overestimate seen with TBW HW in the overall groups was clearly present in the two female subgroups, but did not reach significance in males. Limits of agreement (LOA) by Bland and Altman showed similar and proportionally greater variation between equations and TBW_D in female than males in each subgroup.

Estimates of TBW were all very strongly correlated with TBW_D, but much less so for TBW_0.58Wt than for other equations (Table 4). Correlations of the intermethod differences were performed with mean values of TBW to determine any systematic error related to size of the TBW compartment, and with body mass index (BMI) and the ECW/TBW ratio to determine any relationship between intermethod differences with body fatness or hydration status (Tables 5 and 6). There were negative correlations of TBW_HW – TBW_D and TBW_W – TBW_D, suggesting progressive underestimation of TBW by these equations in the PD group with increase in the TBW volume. A similar relationship was found only for TBW_HW – TBW_D in the controls. TBW_0.58Wt – TBW_D was correlated with BMI and ECW/TBW in both the PD and control groups, suggesting progressive overestimation of TBW by TBW_0.58Wt with increasing fatness and extracellular fluid volume expansion. The only other significant correlations were found in the control group, with TBW Cher – TBW_D and TBW_L – TBW_D correlated with BMI and TBW_HW – TBW_D correlated with ECW/TBW.

### Table 4. Correlations of TBW estimated by anthropometric formulae with TBW_D

<table>
<thead>
<tr>
<th></th>
<th>PD patients</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBW Cher</td>
<td>( r = 0.928 )</td>
<td>( r = 0.968 )</td>
</tr>
<tr>
<td>TBW Chum</td>
<td>( r = 0.923 )</td>
<td>( r = 0.946 )</td>
</tr>
<tr>
<td>TBW HW</td>
<td>( r = 0.924 )</td>
<td>( r = 0.929 )</td>
</tr>
<tr>
<td>TBW L</td>
<td>( r = 0.928 )</td>
<td>( r = 0.965 )</td>
</tr>
<tr>
<td>TBW W</td>
<td>( r = 0.923 )</td>
<td>( r = 0.957 )</td>
</tr>
<tr>
<td>TBW_0.58Wt</td>
<td>( r = 0.927 )</td>
<td>( r = 0.955 )</td>
</tr>
<tr>
<td>TBW_0.58Wt</td>
<td>( r = 0.765 )</td>
<td>( r = 0.702 )</td>
</tr>
</tbody>
</table>

All relationships of significance \( P < 0.0001 \).
of populations used to derive TBW prediction equations. Body fat content is also affected by disease factors, being greater in PD than haemodialysis patients [16] and in subjects with diabetes (a common cause of CRF).

We, and others, have previously demonstrated significant differences between anthropometric equations for TBW estimation and gold-standard dilution techniques in PD [4,17–19]. In relation to the modest variability in clearances achieved with PD, differences techniques in PD [4,17–19]. In relation to the modest significant differences between anthropometric equations derived in specific renal disease populations.

This has led to the development of further equations derived in more contemporary populations, including equations derived in specific renal disease populations. The characteristics of the various equations, including terms utilised, populations they were derived in and reference method for estimating TBW, are summarised in Table 7.

Mean values for anthropometric estimates of TBW all tended to be higher than TBWD. This difference was significant in both PD and control groups for TBWCher and TBWChum, but not for TBWW or TBWL. Whilst this difference was modest for TBWCher and TBWChum, it was most marked for TBWCher and TBWChum. Previous studies have shown TBWCher to be similar to [6], modestly increased [17] or modestly decreased [18] in PD patients compared with dilution methods. Arkouche et al. [19] found TBWCher to produce higher values of TBW than estimates by H218O dilution but not TBWD [19]. Lee et al. [6] also found no significant difference between mean TBWCher and TBWD compared with BIA in haemodialysis patients. Tzamaloukas et al. [20] have shown TBWCher to

### Table 6. Correlations of differences of TBW estimated by anthropometric equations from TBWD with TBW, BMI and ECW/ICW ratio for control subjects

<table>
<thead>
<tr>
<th>Equation and year</th>
<th>Factors</th>
<th>Population derived from</th>
<th>Measurement of TBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chertow et al. [5] 1997</td>
<td>Height, weight, age, gender, diabetes</td>
<td>USA haemodialysis patients (3009 subjects)</td>
<td>Whole body single frequency bioelectrical impedance (pre-dialysis)</td>
</tr>
<tr>
<td>Chumlea et al. [3] 2001</td>
<td>Height, weight, age, gender</td>
<td>Healthy USA subjects (1695 subjects)</td>
<td>3H2O and 2H2O dilution</td>
</tr>
<tr>
<td>Hume and Weyers [2] 1971</td>
<td>Height, weight, gender</td>
<td>Assorted cases, some with medical conditions but no evidence of fluid retention (60 subjects)</td>
<td>3H2O dilution</td>
</tr>
<tr>
<td>Johansson et al. [4] 2001</td>
<td>Height, weight, age, gender</td>
<td>Swedish PD patients (165 subjects)</td>
<td>3H2O dilution</td>
</tr>
<tr>
<td>Lee et al. [6] 2001</td>
<td>Height, weight, gender</td>
<td>Korean haemodialysis patients (101 subjects)</td>
<td>Segmental bioelectrical impedance (post-dialysis)</td>
</tr>
<tr>
<td>Watson et al. [1] 1980</td>
<td>Height, weight, age, gender</td>
<td>Data combined from selection of studies of normal subjects (723 subjects)</td>
<td>Mixture of 3H2O dilution, 3H2O dilution, antipyrine dilution and urea dilution</td>
</tr>
</tbody>
</table>
exceed TBW\textsubscript{W} by 3.5 l in PD patients and Lee et al. [6] have shown TBW\textsubscript{Cher} to overestimate TBW estimated by BIA by \sim 4 l in haemodialysis patients and healthy controls. These are comparable with the overestimate we observed of TBW\textsubscript{Cher} compared with TBW\textsubscript{W} and TBW\textsubscript{D}. It is of significance that TBW\textsubscript{Cher} was derived by measurements of TBW by BIA in a large population of haemodialysis patients, with BIA being performed prior to a dialysis session. At this time, TBW will have been at its highest in most patients, prior to fluid removal by dialysis. Thus, this equation may overestimate TBW when applied to subjects where TBW is likely to represent a lower proportion of body weight. Also, differences in body composition (e.g. related to body fat and racial differences) between the North American population in which TBW\textsubscript{Cher} was derived and our European population may be important. The use of bioelectrical impedance, the results of which may differ significantly in individuals from reference methods [17–19], as a reference method rather than isotope dilution may also have contributed to the differences observed.

The Bland and Altman comparisons show very significant errors in estimating TBW in individual subjects. The ranges of these differences are consistently greater in the PD group than healthy control subjects. The magnitude of the range of 95% LOA for TBW\textsubscript{W} were of very similar magnitude to those described in previous works by ourselves [17], Johansson et al. [4] and Arkouche et al. [19]. Even greater ranges were reported by the study of Wong et al. [18], which found larger ranges for individual agreements in obese compared with non-obese sub-groups, demonstrating the importance of variable body fatness. In the two-compartment model of body composition, fat is anhydrous, whereas FFM has water as its dominant component, so variation in ratio of body fat and FFM would be expected to have a major impact on prediction of TBW, with over-estimation of TBW in obesity. This would be most significant in TBW\textsubscript{0.58W}, which makes no account for body fatness. Hence, the discrepancy seen with this estimate and the strong systematic error related to BMI are entirely to be expected. Differences in body fat will also be a major factor underlying effects of gender. In particular, greater body fat in women will explain the greater overestimate with TBW\textsubscript{0.58W} in females. Increasing body fat is associated with ECW expansion [13], which explains the relationship of TBW\textsubscript{0.58W} – TBW\textsubscript{D} with ECW/TBW in both PD and control groups. Interestingly, we did not identify major differences in hydration in PD subjects compared with controls, suggesting that overhydration is not an inevitable feature in these patients. The presence of subjects with more abnormal hydration would have increased the degree of error of estimation observed. It is also of note that the ratio of ECW/TBW was higher than traditionally quoted in the literature.

Thus, variability in body composition between individuals cannot be sufficiently accounted for by anthropometric equations to allow precise estimation of TBW. This is especially marked in patients with conditions such as advanced renal failure and dialysis, which affect body composition. The factors included in these equations may partly account for the variability of body fat (which is anhydrous and thus an important determinant of the proportion of body weight accounted for by TBW) but are unlikely to be sensitive to variable hydration. Variations in the performance of these equations when applied in our study populations may relate to the differences in methodology and subject characteristics in the original derivation of the equations.

This major limitation in estimating TBW must be considered in future decisions about the most appropriate methods of describing dialysis adequacy and solute clearances in individual patients. Whilst it seems logical to normalise clearances to measures reflecting individual patient size, such normalisation will produce a degree of arbitrary variability. Thus, K\textsubscript{t}/V may be useful for observing changes within an individual or comparing groups. However, caution must be applied in interpreting individual clearances normalised in this way, for example when comparing values to targets for clearance as significant amounts of variability may reflect the normalisation procedure rather than biological effects. Given the large experience with the Watson equation, none of the alternatives provide a sufficient benefit to justify change (at least in patients with similar characteristics to our study group). TBW estimated as a fixed proportion of body weight produces unacceptably inaccurate values with systematic error related to fatness and hydration and should be abandoned from clinical practice.

Acknowledgements. This study was supported by a project grant awarded by the United Leeds Teaching Hospitals Trust Special Trustees.

References

Equations for estimation of total body water in peritoneal dialysis

\[ \text{TBW} = -(0.07493713 \times \text{age}) - (1.01767792 \times \text{gender}) + (0.12703384 \times \text{height}) - (0.04012056 \times \text{weight}) + (0.57894981 \times \text{diabetes}) - (0.0067247 \times \text{weight}^2) - (0.03486146 \times \text{age} \times \text{gender}) + (0.11262857 \times \text{gender} \times \text{weight}) + (0.00104135 \times \text{age} \times \text{weight}) + (0.00186104 \times \text{height} \times \text{weight}) \]

Where for gender male = 1; diabetes = 1

Chumlea \textit{et al.}[3] (equations for white subjects)

\[
\begin{align*}
\text{Male: } \text{TBW} &= 23.04 - (0.03 \times \text{age}) + (0.50 \times \text{weight}) - (0.62 \times \text{BMI}) \\
\text{Female: } \text{TBW} &= -10.50 - (0.01 \times \text{age}) + (0.20 \times \text{weight}) + (0.18 \times \text{height})
\end{align*}
\]

Hume and Weyers [2]

\[
\begin{align*}
\text{Male: } \text{TBW} &= (0.194786 \times \text{height}) + (0.296785 \times \text{weight}) - 14.012934 \\
\text{Female: } \text{TBW} &= (0.34454 \times \text{height}) + (0.183809 \times \text{weight}) - 35.270121
\end{align*}
\]

Johansson \textit{et al.}[4]

\[
\begin{align*}
\text{Male: } \text{TBW} &= -10.759 - (0.078 \times \text{age}) + (0.312 \times \text{weight}) + (0.192 \times \text{height}) \\
\text{Female: } \text{TBW} &= -29.994 - (0.0004 \times \text{age}) + (0.214 \times \text{weight}) + (0.294 \times \text{height})
\end{align*}
\]

Lee \textit{et al.}[6]

\[
\begin{align*}
\text{Male: } \text{TBW} &= -28.3497 + (0.243057 \times \text{height}) + (0.366248 \times \text{weight}) \\
\text{Female: } \text{TBW} &= -26.6224 + (0.262513 \times \text{height}) + (0.232948 \times \text{weight})
\end{align*}
\]

Watson \textit{et al.}[1]

\[
\begin{align*}
\text{Male: } \text{TBW} &= 2.447 - (0.09156 \times \text{age}) + (0.1074 \times \text{height}) + (0.3362 \times \text{weight}) \\
\text{Female: } \text{TBW} &= -2.097 + (0.1069 \times \text{height}) + (0.2466 \times \text{weight})
\end{align*}
\]

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Appendix

Details of the prediction equations for TBW investigated in this paper are shown below.