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Assessment of total body water from anthropometry-based equations using bioelectrical impedance as reference in Korean adult control and haemodialysis subjects

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Abstract
Background. Several indirect prediction equations to estimate total body water (TBW) with simple demographic and anthropometric data are commonly used by researchers and dialysis units. These equations are largely based on observations in subjects of the Western hemisphere. The purpose of this study was to investigate the possible application of anthropometry-based TBW equations to a Korean adult control population and maintenance haemodialysis (HD) patients using multifrequency bioelectrical impedance analysis (BIA) as reference.
Methods. We performed BIA and anthropometric measurements in 67 healthy adults and 101 HD patients. Four anthropometry-based equations were used: 58% of actual body weight (TBW-58), the Watson formula (TBW-W), the Hume formula (TBW-H), and the Chertow formula (TBW-C). Multifrequency BIA was performed at fasting state in controls and after HD.
Results. TBW-BIA was 34.6±6.9 l in control and 29.9±5.1 l in HD patients. TBW-58 and TBW-C gave significantly greater TBWs than TBW-BIA in both control and HD subjects. The correlation coefficients of TBW-BIA with calculated TBWs were lowest in TBW-58 (0.754 in control and 0.856 in HD subjects), and highest in TBW-C (0.944 in control and 0.916 in HD subjects). Mean prediction error was greatest in the Chertow formula for control and HD patients. Mean prediction error, limits of agreement, and root mean square error were lowest between TBW-BIA and TBW-H in control and between TBW-BIA and TBW-W in HD subjects. The correlation coefficient in the Bland–Altman plot was closer to zero and parallel with TBW-W than TBW-H in control and HD subjects.
Conclusion. Currently available TBW equations overestimate TBW in both Korean normal control subjects and HD patients. Among them, the Watson formula appears to be the closest to TBW and to have the least bias. Based on this analysis, it is reasonable to use the Watson formula for the calculation of TBW in Korean adult control and HD subjects until an Asian-based TBW equation is available.

Keywords: haemodialysis; indirect methods; multifrequency bioimpedance; total body water

Introduction

Water is the major chemical component of the body and an essential medium of the body's internal environment. Total body water (TBW) is constantly maintained in normal subjects, although it fluctuates approximately ±5% daily because of ongoing physiological processes and the consumption of food and beverages. However, TBW is largely altered by disease, especially in renal insufficiency.

Measurement of TBW is frequently performed to evaluate the body composition and nutritional status in normal subjects and end-stage renal disease patients. In dialysis patients, the need for an accurate measurement of TBW is particularly important, as it directly relates to urea kinetic modelling and has implications for the assessment of dry weight. The accurate measurement of TBW is difficult, requiring isotopic dilution techniques which are not easily applicable to the clinical setting.

Therefore, several indirect methods of estimating TBW with simple demographic and anthropometric data are commonly employed by researchers and dialysis units, using one of the following: a constant fraction of body weight, i.e. 58% of actual body weight [1]; the Watson formula [2], the Hume formula [3], and the Chertow formula [4]. Among them, the first three were derived from normal controls whereas the Chertow formula has been from haemodialysis (HD) patients. However, these equations are largely based on subjects of the Western hemisphere. It is unclear

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whether these equations are also applicable to Asian subjects.

The purpose of this study was to investigate whether anthropometry-based TBW equations can be applied to the Korean adult control subjects and maintenance HD patients using multifrequency bioelectrical impedance analysis (BIA) as reference.

Subjects and methods

Study subjects

We performed BIA and anthropometric measurements cross-sectionally in June 1998 at Inha University Hospital, Inchon, Korea. Sixty-seven healthy adults and 101 stable HD patients on HD for more than 3 months, participated in this study. Patients with clinical signs of overhydration (peripheral pitting oedema and neck vein distension), those with congestive heart failure, infection, hemiplegia, or admission within 3 months, were excluded, as were amputees and those aged <18 years.

In healthy controls, the study was performed in the fasting state and after urination. In HD patients, the study was performed 30–60 min after a mid-week dialysis session (Wednesday or Thursday) because the assessment of TBW by BIA immediately post-dialysis overestimates the actual volume of ultrafiltrate removed. Height was measured to the nearest 0.1 cm using a linear height scale, and body weight was measured to the nearest 0.1 kg using an electronic weight scale. Mean values of two measurements were used for the analysis of data.

We also used extracellular water (ECW)/TBW ratio as a tool of hydration status [5]. Patients in whom ECW/TBW ratios were below the upper limit of control were also analysed using the statistical methods given below.

Anthropometry-derived TBW calculations

TBW was calculated as 0.58 times actual body weight (kg) (TBW-58) [1], by the Watson formula (TBW-W) [2], by the Hume formula (TBW-H) [3], and the Chertow formula (TBW-C) [4].

Watson formula

Male: $\text{TBW-W} = 2.447 - (0.09156 \times \text{age}) + (0.1074 \times \text{height}) + (0.3362 \times \text{weight})$

Female: $\text{TBW-W} = -2.097 + (0.1069 \times \text{height}) + (0.2466 \times \text{weight})$

Hume formula

Male: $\text{TBW-H} = (0.194786 \times \text{height}) + (0.296785 \times \text{weight}) - 14.012934$

Female: $\text{TBW-H} = (0.34454 \times \text{height}) + (0.183809 \times \text{weight}) - 35.270121$

Chertow formula

$$\begin{aligned}\text{TBW-C} = {} & -0.07493713 \times \text{age} - 1.01767992 \times \text{male} + \\ & 0.12703384 \times \text{height} - 0.04012056 \times \text{weight} + \\ & 0.57894981 \times \text{weight} + 0.57894981 \times \text{diabetes} - \\ & 0.00067247 \times \text{weight}^2 - 0.03486146 \times (\text{age} \times \text{male}) + \\ & 0.11262857 \times (\text{male} \times \text{weight}) + \\ & 0.00104135 \times (\text{age} \times \text{weight}) + \\ & 0.0186104 \times (\text{height} \times \text{weight}),\end{aligned}$$

where male $=1$ and diabetes $=1$.

TBW measurement by BIA (TBW-BIA)

For determination of TBW-BIA we used a prototype segmental BIA (Inbody 2.0®, Biospace Co. Ltd, Seoul, Korea), which has eight tactile electrodes, the measurement of patients being carried out in the upright posture. With the patient standing on the sole electrodes and gripping the hand electrodes, the microprocessor-controlled switches and impedance analyser were started and segmental resistances of right arm, left arm, trunk, right leg, and left leg were measured at four frequencies (5, 50, 250 and 500 kHz). Thus a set of 20 segmental resistances was measured for an individual. With these data, TBW was calculated from the sum of each body segment, using equations in the BIA software. The procedure was performed in 3 min or less. To analyse the repeatability of the study, BIA was performed five times at intervals of 3 min in nine HD patients. The mean of the standard deviation and the coefficient of variation of each set of readings were 0.10 and 0.29%.

Statistical analysis

Data were expressed as mean ± SD. TBWs were compared with ANOVA. To assess the agreement between TBW-BIA and the calculated TBWs, each TBW derived from anthropometry was compared with TBW-BIA using correlation coefficient (r), mean prediction error, limits of agreement, root mean square error (RMSE) and Bland–Altman plots [6]. High correlation means that the measurements by the two methods are linearly related. However, this high correlation does not mean that the two methods agree. With Bland–Altman plots, which calculate differences against mean of the measurements of two methods, we can summarize the lack of agreement by calculating the bias, estimated by mean prediction error and the standard deviation of the differences. The mean prediction error is an indication of bias but not accuracy. The limits of agreement are only estimates of the values which apply to the whole population. The RMSE value is used as a measure of the goodness of fit of an equation. If there is more than one equation to fit the data, the one with the smallest RMSE value has the highest precision. Correlation was described with the Pearson coefficient (r). The equations used for mean prediction error and RMSE are as follows:

$$\text{Mean prediction error} = [\Sigma(\text{TBW-BIA-calculated TBW})]/n,$$

$$\text{RMSE} = \sqrt{(\Sigma(\text{calculated TBW-TBW-BIA})^2/n)},$$

where n is the sample size. The limits of agreement were defined as the mean prediction error (ME) ± 2 SD of the ME. A 0.05 level of significance was used in all statistical analyses. To quantitate the degree of bias in the four formulae, we compared the correlation coefficients of the respective residuals and averages. The closer the correlation coefficient of Bland–Altman plot is to zero, the less the bias.

Results

Subject characteristics are presented in Table 1. In HD patients, mean ages were 50.0 ± 13.8 years, male to

Table 1. Baseline characteristics of study subjects

	HD (n=101)	Controls (n=67)
Age (years)	50.1±13.8	43.6±16.5*
Sex (% female)	51.5	34.3*
HD duration (months)	15.2±7.4	–
Diabetes (%)	20.8	0
Height (cm)	161.3±8.0	165.0±9.4*
Weight (kg)	55.1±8.3	65.9±11.7*
BMI (kg/m^2)	20.9±3.5	24.2±3.5*

HD, haemodialysis; BMI, body mass index.
*$P<0.05$ *vs* HD.

female ratio was 1 : 1.1, diabetics 21 (20.8%), and mean duration of dialysis was 15.2±7.4 months. Compared to controls, HD patients had significantly less height, body weight, body mass index, and fat mass, and comprised more females.

The correlation coefficients of TBW-BIA with calculated TBWs were lowest in TBW-58 (0.856 in control and 0.754 in HD), and highest in TBW-C (0.944 in control and 0.916 in HD) (Figures 1 and 2). Correlation coefficients were slightly higher in TBW-H, compared with TBW-W in both groups. TBW-C showed a considerable degree of separation with line of identity in both control and HD patients, in spite of the highest correlation coefficient. Figures 1 and 2 also show a trend that anthropometry-derived TBWs overestimate, as TBW-BIAs went to the left and reached to the line of identity or even across the line of identity, and TBW-BIAs went to the right in abscissa.

Table 2 shows the results of TBW measurements. TBW-BIA was 34.6±6.9 l in control and 29.9±5.1 l in HD patients. Among them, TBW-58 and TBW-C gave significantly greater TBWs than TBW-BIA in both control and HD subjects.

The Bland–Altman method gives a visual representation (Figures 3 and 4). In control, mean prediction errors and limits of agreements were −1.78 l and (3.08 ~ −6.64) l in TBW-W, −1.55 l and (3.27 ~ −6.37) l in TBW-H, −4.26 l and (0.36 ~ −8.88) l in TBW-C, and −3.67 l and (3.69 ~ −11.03) l in TBW-58 (Table 3). In HD patients, mean prediction errors and limits of agreements were −1.37 l and (3.19 ~ −5.93) l in TBW-W,

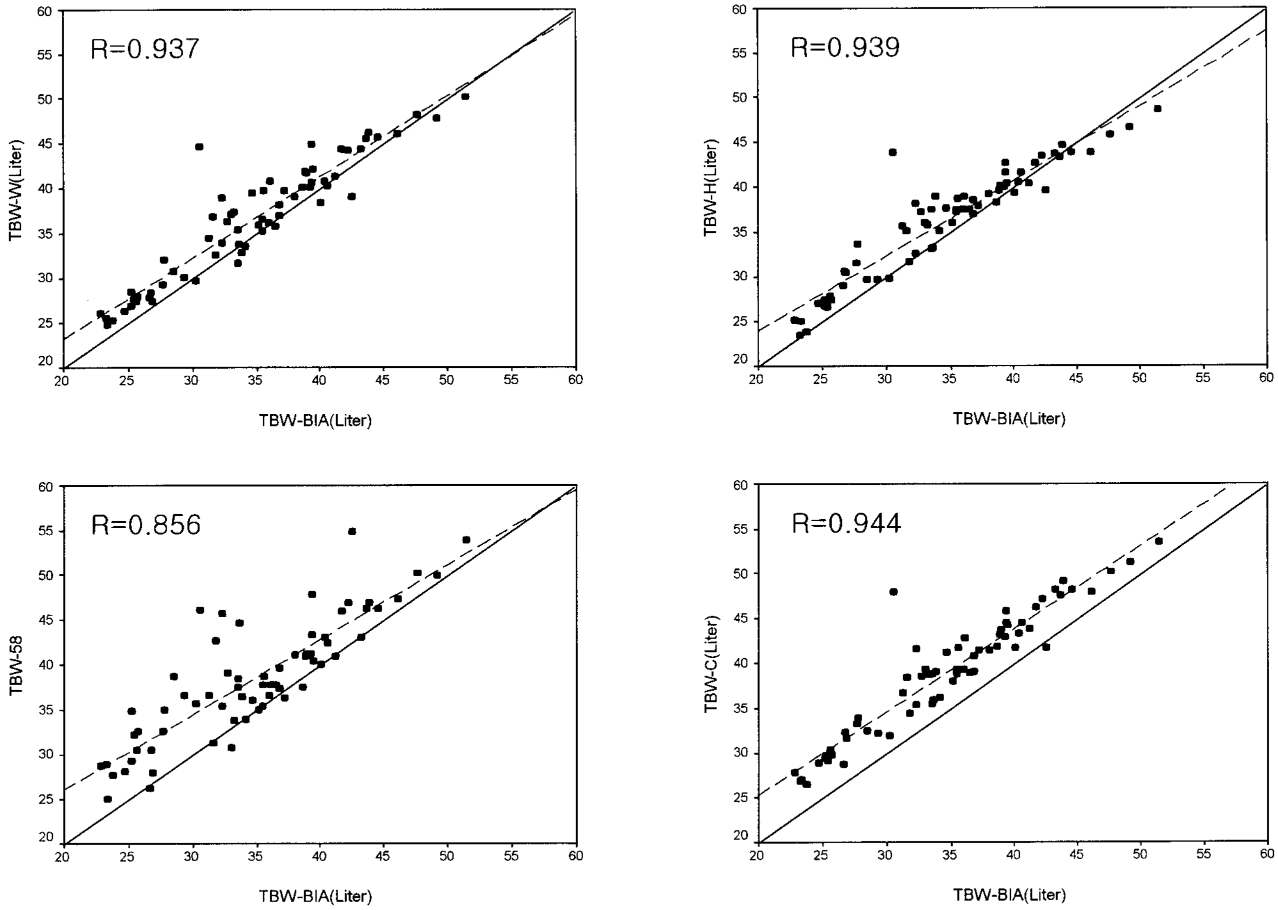

Fig. 1. Correlation between TBW by prediction equations and TBW by BIA in healthy control subjects. TBW-W, TBW by Watson formula; TBW-H, TBW by Hume formula; TBW-58, TBW of 58% of actual body weight; TBW-C, TBW by Chertow formula; TBW-BIA, TBW by BIA. Dotted line = linear regression line, solid line = line of identity.

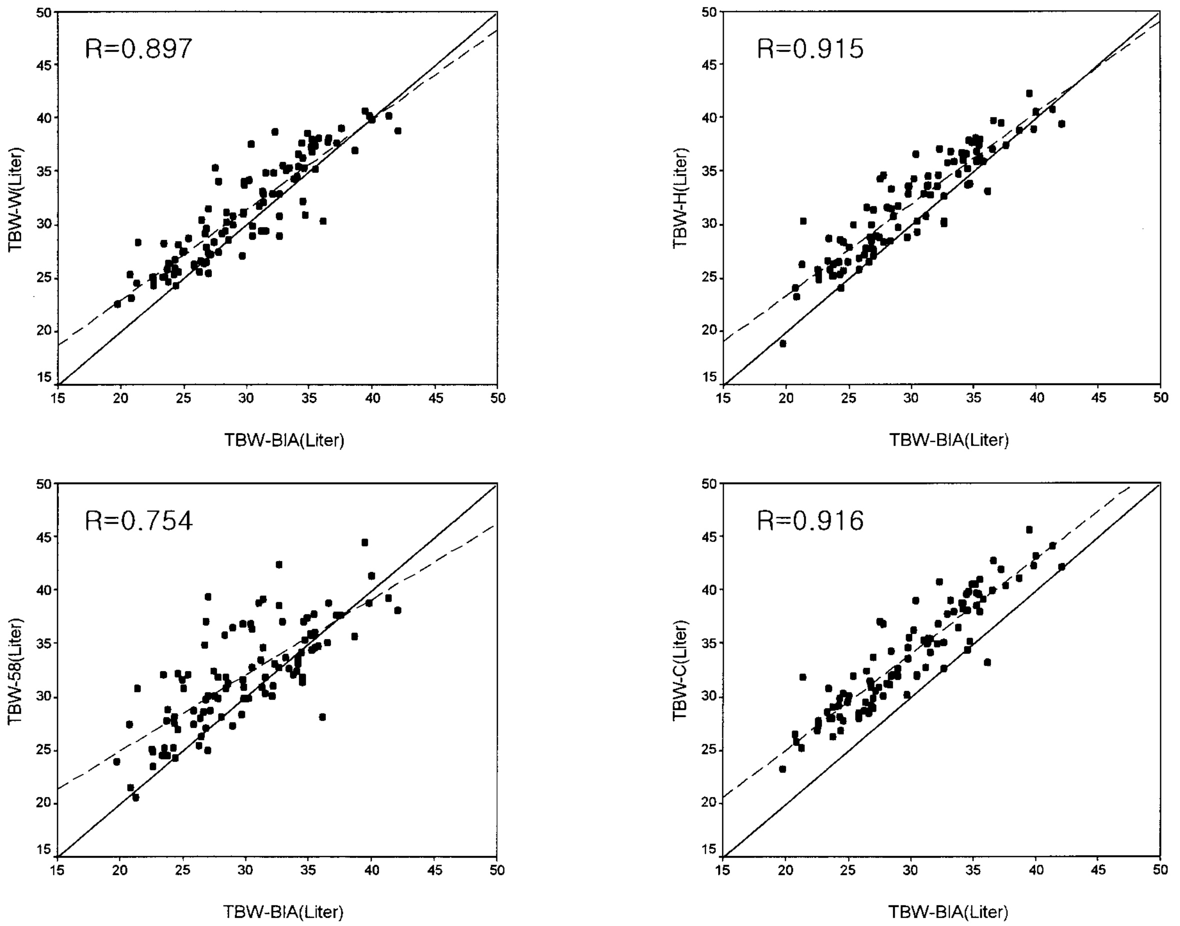

Fig. 2. Correlation between TBW by prediction equations and TBW by BIA in HD patients. TBW-W, TBW by Watson formula; TBW-H, TBW by Hume formula; TBW-58, TBW of 58% of actual body weight; TBW-C, TBW by Chertow formula; TBW-BIA, TBW by BIA. Dotted line = linear regression line; solid line = line of identity.

Table 2. Results of TBW by different equations

TBW (Litre)	Control	HD
	Mean ± SD	Mean ± SD
TBW–BIA	34.6 ± 6.9	29.9 ± 5.1
TBW–W	36.4 ± 6.7	31.3 ± 4.8
TBW–H	36.1 ± 6.2	31.8 ± 4.8
TBW–58	38.2 ± 6.8*	31.9 ± 4.8**
TBW–C	38.8 ± 6.8*	33.9 ± 5.0**

$^*P<0.05$ *vs* TBW–BIA in control; $^{**}P<0.05$ *vs* TBW–BIA in HD. TBW–BIA, TBW by BIA; TBW–W, TBW by Watson formula; TBW–H, TBW by Hume formula; TBW–58, TBW by 0.58 × body weight.

−1.90 l and (2.24∼−6.04) l in TBW-H, −3.98 l and (0.18∼−8.14) l in TBW-C, −2.05 l and (4.97∼−9.07) l in TBW-58.

Mean prediction error was greatest in the Chertow formula (3.98 l in HD and 4.26 l in control) (Table 3). Mean prediction error and limits of agreement was lowest between TBW-BIA and TBW-H in control and between TBW-BIA and TBW-W in HD subjects. RMSE was lowest between TBW-BIA and TBW-H (2.85) in control and TBW-W (2.65) in HD. The correlation coefficients in the Bland–Altman plot was closer to zero and parallel with TBW-W ($r=0.099$ and 0.135) than TBW-H ($r=0.313$ and 0.168) in control and HD subjects. When the patients were restricted to those ($n=58$) in whom ECW/TBW ratios were below upper limit (0.348) of control, the results were similar.

We developed a new equation based on the data in HD patients.

Male: $\text{TBW} = -28.3497 + 0.243057 \times \text{Height (cm)} + 0.366248 \times \text{Body weight (kg)}$

Adjusted R^2 is 0.7535.

Female: $\text{TBW} = -26.6224 + 0.262513 \times \text{Height (cm)} + 0.232948 \times \text{Body weight (kg)}$

Adjusted R^2 is 0.6758.

Discussion

In this study all of the anthropometry-based equations overestimated TBW in both control and HD subjects. TBW-58 and TBW-C gave significantly greater TBWs than TBW-BIA in both control and HD subjects.

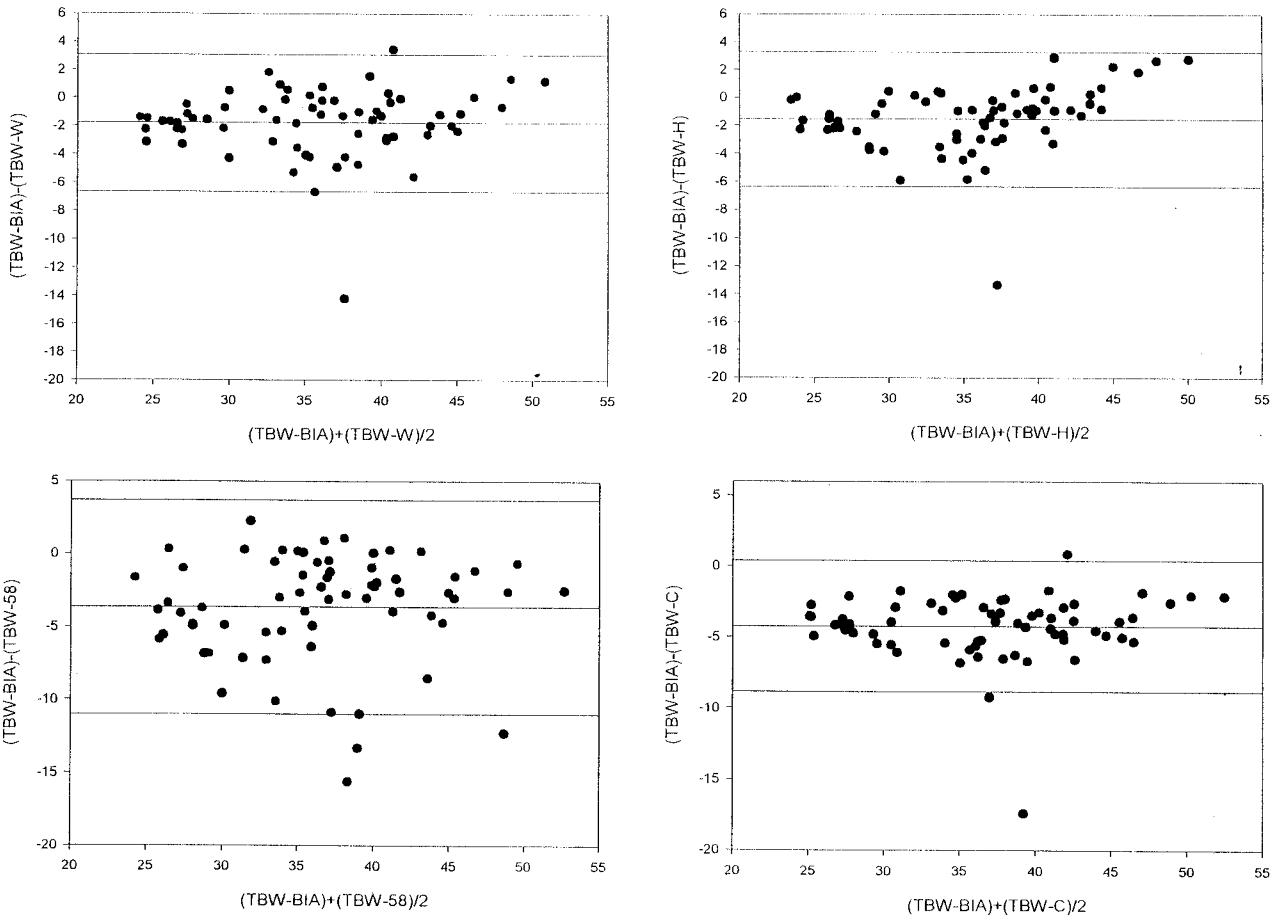

Fig. 3. Graphical plot of the Bland–Altman representation of the difference between four anthropometry-based TBW and TBW-BIA in control subjects. The three horizontal lines indicate upper limit of agreement, mean prediction error, and lower limit of agreement. TBW-W, TBW by Watson formula; TBW-H, TBW by Hume formula; TBW-58, TBW of 58% of actual body weight; TBW-C, TBW by Chertow formula; TBW-BIA, TBW by BIA.

Mean prediction errors, limits of agreement and RMSE were relatively small and comparable in the Watson and the Hume formulae in control and HD. However, the degree of bias was greater in the Hume formula than in the Watson formula.

These results were similar to the study of Borgonha *et al.* [7], in which anthropometry-based prediction equations overestimated TBW from 0.87 ± 2.49 to 2.47 ± 2.57 kg, compared to the deuterium dilution method in Indian men. In the study of Arkouche *et al.* [8] with peritoneal dialysis patients, they compared the Watson formula and 58% of body weight method with O^{18} method; 58% of body weight method considerably overestimated TBW (mean prediction error + 5.4 kg). The best prediction of TBW was obtained with the Watson formula in their study [8], which produced results similar to ours.

This overestimation seems to have originated from different ethnic backgrounds or body builds. The currently available equations are derived from healthy Western people. Compared to a Caucasian population, the Asians were smaller, had a lower body weight and lower values of body water compartments. Therefore it is natural that systematic errors occur when applying prediction formulae from a reference population to another population under study. Indeed, Borgonha *et al.* [7] found that the Hume formula overestimated TBW by 2.47 ± 2.57 kg in Indian men. Deurenberg *et al.* [9] pointed out that body composition equations should be corrected when applying them to another race with different body build. Zillikens and Conway [10] also showed that TBW was significantly underestimated in black subjects by using equations developed in white populations. Arkouche *et al.* [8] noted that the extreme values were obtained for the Asian patients by the Watson formula. In this study, TBW-BIAs of healthy control were small compared to those of the study of Watson *et al.* [2] and even smaller than those of The Fels Study in 1999 [11]. In HD patients, TBWs were also small compared to Western HD patients [12]. Most researchers and dialysis centres utilize one of several available regression equations for the calculation of TBW, which incorporate age, gender, height, and weight. In dialysis patients, the overestimation of TBW causes the inaccurate measurement of HD adequacy, that is, the underestimation of Kt/V_{urea}. Indeed, prediction equations are population-specific, and validation is required when these equations are

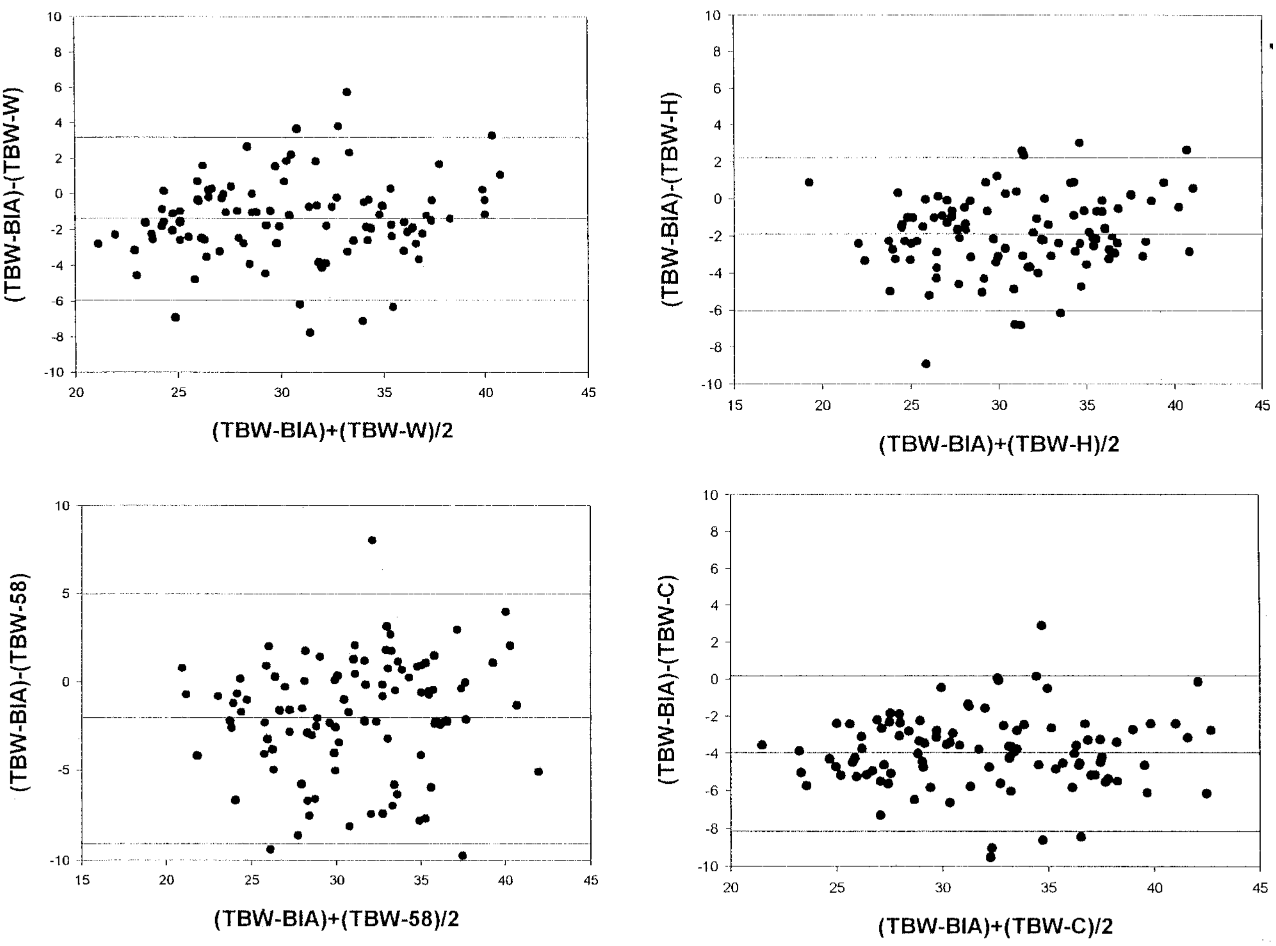

Fig. 4. Graphical plot of the Bland–Altman representation of the difference between four anthropometry-based TBW and TBW-BIA in HD patients. The three horizontal lines indicate upper limit of agreement, mean prediction error, and lower limit of agreement. TBW-W, TBW by Watson formula; TBW-H, TBW by Hume formula; TBW-58, TBW of 58% of actual body weight; TBW-C, TBW by Chertow formula; TBW-BIA: TBW by BIA.

Table 3. Mean prediction error and root mean square prediction error for measuring TBW by four different equations, compared to TBW–BIA

	TBW–58	TBW–W	TBW–H	TBW–C
Control				
n	67	67	67	67
ME	−3.67	−1.78	−1.55	−4.26
Limits of agreement				
Upper	3.69	3.08	3.27	0.36
Lower	−11.03	−6.64	−6.37	−8.88
RMSE	5.17	3.00	2.85	4.84
HD				
n	101	101	101	101
ME	−2.05	−1.37	−1.90	−3.98
Limits of agreement				
Upper	4.97	3.19	2.24	0.18
Lower	−9.07	−5.93	−6.04	−8.14
RMSE	4.04	2.65	2.8	4.49

ME (mean prediction error), (TBW–BIA)—other equations; RMSE, root mean square prediction error; TBW–BIA, TBW by BIA; TBW–W, TBW by Watson formula; TBW–H, TBW by Hume formula; TBW–58, TBW by 0.58 × actual body weight; TBW–C, TBW by Chertow formula.

applied to a new group of subjects [13]. Thus, Asian-specific anthropometry-derived TBW equations are needed. Researchers should also keep in mind this problem of the evaluation of adequacy in Asian population.

We used segmental BIA, which was the prototype of multifrequency BIA as the reference method for the measurement of TBW. The gold standard is the isotope dilution method, but it is invasive and technically time consuming. On the other hand, BIA is a quick, safe, and non-invasive technique that requires little help from the patient. Furthermore, dialysis centres require simple and reliable measures of TBW because the application of sophisticated direct measurement methods are not practical.

Numerous investigators have shown that TBW can be accurately and reliably estimated by BIA in normal adults. In dialysis patients, however, several studies reported inaccuracy of BIA on the assessment of TBW in dialysis patients [8,14,15]. However, BIAs used in these studies were generally single-frequency BIA. Recently, multifrequency BIA (MFBIA), by which it is possible to distinguish between intracellular and extracellular spaces, was introduced to measure more precisely the body volume. MFBIA was superior to single-frequency BIA in the evaluation of body water distribution in end-stage renal disease and other clinical disorders of fluid volume and/or distribution [16] and validated for assessment of body water in HD patients [17]. However, BIA has not found universal acceptance even with the introduction of MFBIA. The major reason is that no single algorithm has been developed which can be applied to all subject groups. This may be due, in part, to the commonly used wrist-to-ankle protocol, the so-called whole body BIA, which is not indicated by the basic theory of bioimpedance, where the body is considered as five interconnecting cylinders. In addition, significant errors may occur in the measurement of TBW from whole-body BIA during fever, in the supine or standing positions, during cramps, with lymphoedema, or in the presence of a native arteriovenous fistula, a catheter in a central vein, or a graft in HD patients [18].

With this background, segmental BIA appears to be a promising technique to be evaluated in maintenance dialysis patients [13]. Although we did not validate TBW estimation by segmental BIA with a gold standard method, segmental BIA has already been validated as a technique to assess dry weight [19]. In addition, errors from whole body BIA estimation were reduced by the use of segmental BIA [20].

In summary, currently available TBW equations overestimate TBW in both Korean normal control subjects and HD patients. The Watson formula appears to be the closest to TBW and to have least bias. Based on this analysis, it is reasonable to use the Watson formula for the calculation of TBW in Korean adult control and HD subjects until the Asian-based TBW equation is available.

References

1. Keshaviah PR. Quantitative approaches to prescribing peritoneal dialysis. In: La Greca G, Ronco C, Feriani M, Chairamonte S, Conz P, eds. *Peritoneal Dialysis: Proceedings of the Fourth International Course on Peritoneal Dialysis*. Wichtig Editore, Milano, 1991; 53–60
2. Watson PE, Watson ID, Batt R. Total body water volumes for adult males and females estimated from simple anthropometric measurements. *Am J Clin Nutr* 1980; 33: 27–39
3. Hume R, Weyers E. Relationship between total body water and surface area in normal and obese subjects. *J Clin Pathol* 1971; 24: 234–238
4. Chertow GM, Lazarus JM, Lew NL, Ma L, Lowrie EG. Development of a population-specific regression equation to estimate total body water in hemodialysis patients. *Kidney Int* 1997; 51: 1578–1582
5. Oe B, De Fijter WM, De Fijter CWH *et al.* Detection of hydration status by total body bioelectrical impedance analysis (BIA) in patients on hemodialysis. *Int J Artif Organs* 1997; 20: 371–374
6. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; 1: 307–310
7. Borgonha S, Petracchi C, Ferro Luzzi A, Shetty PS, Kurpad AV. Prediction of total body water in Indian men from anthropometry and bioelectrical impedance using deuterium dilution as reference. *Ann Hum Biol* 1997; 24: 355–361
8. Arkouche W, Fouque D, Pachiaudi C *et al.* Total body water and body composition in chronic peritoneal dialysis patients. *J Am Soc Nephrol* 1997; 8: 1906–1914
9. Deurenberg P, Wolde-Gebriel Z, Schouten FJM. Validity of predicted total body water and extracellular water using multifrequency bioelectrical impedance in an Ethiopian population. *Ann Nutr Metab* 1995; 39: 234–241
10. Zillikens MC, Conway JM. The estimation of total body water by bioelectrical impedance analysis in blacks. *Am J Hum Biol* 1991; 3: 25–32
11. Chumlea WC, Guo SS, Zeller CM, Reo NV, Siervogel RM. Total body water data for white adults 18 to 64 years of age: The Fels Longitudinal Study. *Kidney Int* 1999; 56: 244–252
12. Chertow GM, Lazarus JM, Lew NL, Ma L, Lowrie EG. Bioimpedance norms for the hemodialysis population. *Kidney Int* 1997; 52: 1617–1621
13. Foster KR, Lukaski HC. Whole-body impedance, what does it measure? *Am J Clin Nutr* 1996; 64[Suppl]: S388–396
14. de Fijter WM, de Fijter CWH, Oe PL, ter Wee PM, Donker AJM. Assessment of total body water and lean body mass from anthropometry, Watson formula, creatinine kinetics, and body electrical impedance compared with antipyrine kinetics in peritoneal dialysis patients. *Nephrol Dial Transplant* 1997; 12: 151–156
15. Kong CH, Thompson CM, Lewis CA, Hill PD, Thompson FD. Determination of total body water in uraemic patients by bioelectrical impedance. *Nephrol Dial Transplant* 1993; 8: 716–719
16. Cha K, Chertow GM, Gonzalez J, Lazarus JM, Wilmore DW. Multifrequency bioelectrical impedance estimates the distribution of body water. *J Appl Physiol* 1995; 79: 1316–1319
17. Ho T, Kushner R, Schoeller D, Gudivaka R, Spiegel D. Bioimpedance analysis of total body water in hemodialysis patients. *Kidney Int* 1994; 46: 1438–1442
18. Di Iorio BR, Terracciano V, Bellizzi V. Bioelectrical impedance measurement: errors and artifacts. *J Ren Nutr* 1999; 9: 192–197
19. Kouw PM, Olthof CG, ter Wee PM *et al.* Assessment of post-dialysis dry weight: an application of the conductivity measurement method. *Kidney Int* 1992; 41: 440–444
20. Zhu F, Schneditz D, Levin NW. Sum of segmental bioimpedance analysis during ultrafiltration and hemodialysis reduces sensitivity to changes in body position. *Kidney Int* 1999; 56: 692–699

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