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# Comparison of bioimpedance methods for estimating total body water and intracellular water changes during hemodialysis

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**Abstract**

**Background.** The accurate assessment of body fluid volume is important in many clinical situations. Hannan *et al.* proposed a single-frequency bioimpedance equation (HE) to calculate extracellular water (ECW) and total body water (TBW). There are two equations based on the bioimpedance spectroscopy (BIS) method for the evaluation of body fluid volume: Xitron equations (XE) and body composition spectroscopy equations (BCSE). The aim of the study was to compare the accuracy of these three equations in body fluid volume point estimation in maintenance hemodialysis (MHD) patients.

**Methods.** The BIS method was performed in MHD patients before and after a hemodialysis (HD) session. TBW, ECW and intracellular water (ICW) were calculated by XE, BCSE and HE, respectively. Hydration status (HS) was calculated using inputs of XE, BCSE and HE. ICW before dialysis was compared to ICW after dialysis. The change of TBW and HS using different equations was compared to actual ultrafiltration volume (AUV) that was calculated as weight difference of pre- to postdialysis.

**Results.** Fifty MHD patients (27 females) were included in the study. Significant changes in ICW were observed using the XE and HE method with ultrafiltration (XE: 15.51 ± 5.07 versus 16.17 ± 5.34 L, $P < 0.01$; HE: 17.40 ± 5.13

versus 16.55 ± 4.71 L, $P < 0.01$). However, no significant ICW change was observed using BCSE (17.47 ± 4.35 versus 17.54 ± 4.36 L, $P > 0.05$). ΔTBW_XE and ΔTBW_HE were significantly different from AUV (XE 1.76 ± 0.89 versus 2.46 ± 0.89 L, $P < 0.01$; HE 4.16 ± 1.36 versus 2.46 ± 0.89 L, $P < 0.01$); however, ΔTBW_BCSE was much closer to AUV (2.27 ± 0.90 versus 2.46 ± 0.89 L, $P = 0.129$). The change of HS using inputs of BCSE was also closer to AUV (2.41 ± 0.86 versus 2.46 ± 0.89 L, $P = 1.0$).

**Conclusion.** Our study indicated that BCSE provided a better point estimation of ICW and TBW.

**Keywords:** bioimpedance method; body fluid volume; comparison

## Introduction

The accurate assessment of fluid status and body composition is a major clinical challenge. Body fluid volume determination via bioelectrical impedance methods is easy to perform, noninvasive and rapid. It allows repeated measurements with excellent interobserver reproducibility. Over the years, a number of volume equations converting measured resistance and reactance to volume were published [1]. Some of the methods are single-frequency bioimpedance analyses, and their equations are empirical and simply express total body water (TBW) as a linear function of the resistance index ($H^2/R_{50}$, where $H$ stands for body height and $R_{50}$ stands for resistance at 50 KHz) [2], such as Kushner *et al.* [3], Hannan *et al.* [4], Deurenberg *et al.* [5] and Lukaski *et al.* [6]. The equation proposed by Hannan *et al.* [4] (HE) could estimate both ECW and TBW.

Bioimpedance spectroscopy (BIS) analysis methods have more solid theoretical background since they attempt to incorporate the underlying physical principles when converting resistance and reactance to amount of fluid [7, 8]. Currently, the Cole–Cole model and Hanai principle are mostly used in body fluid calculation. There are two equations by BIS measurement for evaluation of body composition that are both based on the Cole–Cole model and Hanai principle: the Xitron equations (XE) [9, 10] and body composition spectroscopy equations (BCSE) [11]. In XE, the body density and extracellular and intracellular resistivity are assumed to be unchanged, which results in a constant coefficient $K_{\mathrm{ECW}}$ for extracellular water (ECW) calculation. Intracellular water (ICW) is regarded as a function of ECW [9, 10]. The BCSE proposed in 2006 [11] took body mass index (BMI) into account to individualize $K_{\mathrm{ECW}}$ and a coefficient $K_{\mathrm{ICW}}$ for calculating ICW. Nevertheless, ICW was not regarded as a function of ECW.

The aim of the study was to compare the point estimation of body fluid calculation in maintenance hemodialysis (MHD) patients by different bioimpedance equations, XE, BCSE and HE. The principal of the method was that an equation that detected volume change should be equal to a real volume change during hemodialysis (HD) with ultrafiltration. Using this principal, the accuracy of the three equations was compared.

## Methods

### *Patients*

A total of 50 MHD patients from the dialysis center of Peking University First Hospital were studied. All patients had given informed consent. Pregnant women and patients with urine volume >400 mL/day, pacemakers or metallic implants and limb amputation were excluded.

### *Bioimpedance measurement*

Whole-body bioimpedance measurements were performed by Hydra 4200 BIS analyzer (Xitron Technologies Inc., San Diego, CA) in each MHD patient before and after one HD session by the same operator. Each subject was kept in supine position for at least 10 min before the first measurement to allow for equilibration of fluid shifts, and the time delay between the second measurement at the end of dialysis was at least 10 min. Electrodes were placed in a tetra-polar configuration using the right foot and hand in patients with a central catheter or the opposite side in patients using an arteriovenous fistula as vascular access. Proximal (voltage) electrodes were separated by 5 cm from distal (current) electrodes. The electrodes were removed after the post-dialysis measurement was completed. Each measurement was recorded simultaneously in a laptop computer connected to the Hydra analyzer.

Ten consecutive runs were performed within a 1-min period, and 10 pairs of resistance ECW ($R_e$) and resistance ICW ($R_i$) were captured by the software according to the Cole–Cole model. The average of 10 pairs in each $R_e$ and $R_i$ was used to calculate the final $R_e$ and $R_i$. The resistance and reactance at 50 KHz ($R_{50}$ and $X_{50}$) were recorded for HE calculation. TBW resistance Rinfinite ($R_{inf}$) was calculated according to $R_{inf}{}^{-1} = R_e{}^{-1} + R_i{}^{-1}$ [1].

### *Parameters*

Age, height, weight and dialysis vintage were documented in all patients. Weight corrected for clothing was determined by a calibrated scale with an accuracy of 0.1 Kg before and after dialysis.

### *Body fluid volume change estimated by different equations*

Total body fluid volume was calculated using XE [9, 10] and BCSE [11] with the same $R_e$ and $R_i$ value and HE with $R_{50}$ and $X_{50}$. Hydration status (HS) as defined by Chamney *et al.* [12] was calculated using inputs of XE, BCSE and HE. Equations (1) to (5) were XE. ECW and ICW were calculated based on the Hanai principle, where $\rho_{\mathrm{ECW}}$ was the extracellular resistivity (female: 39 Ωcm and male: 40.5 Ωcm) and $\rho_{\mathrm{ICW}}$ was the intracellular resistivity (female: 264 Ωcm and male: 273.9 Ωcm). $H$ was body height (centimeter), Wt was body weight (kilogram) and $D_B$ was body density (1.05 kg L$^{-1}$). $K_B = 4.3$ was a shape factor correcting for a whole-body measurement between wrist and ankle, relating to the relative proportions of the leg, arm, trunk and height. ΔTBW_XE was total body fluid volume change estimated by XE during HD with ultrafiltration according to equation (6). $\mathrm{TBW}_{\text{XE-pre}}$ and $\mathrm{TBW}_{\text{XE-post}}$ were the TBW calculated by XE before and after dialysis, respectively.

$$\mathrm{ECW}_{\mathrm{XE}} = K_{\mathrm{ECW}} \left(\frac{H^2 \cdot \sqrt{\mathrm{Wt}}}{R_e}\right)^{2/3}; \quad (1)$$

$$K_{\mathrm{ECW}} = \frac{1}{1000}\left(\frac{K_B^2 \cdot \rho_{\mathrm{ECW}}^2}{D_B}\right)^{1/3}. \quad (2)$$

In equation (2), $K_{\mathrm{ECW}}$ is a constant (male: 0.306 and female: 0.299).

$$\mathrm{ICW}_{\mathrm{XE}} = \mathrm{ECW}_{\mathrm{XE}} \times \left\{\left[\frac{\rho_{\mathrm{TBW}} \times (R_e + R_i)}{\rho_{\mathrm{ECW}} \times R_i}\right]^{2/3} - 1\right\} \quad (3)$$

$$\rho_{\mathrm{TBW}} = \rho_{\mathrm{ICW}} - (\rho_{\mathrm{ICW}} - \rho_{\mathrm{ECW}}) \times \left(\frac{R_i}{R_e + R_i}\right)^{2/3} \quad (4)$$

$$TBW_{XE} = ECW_{XE} + ICW_{XE} \quad (5)$$

$$\Delta TBW_{XE} = TBW_{XE-pre} - TBW_{XE-post} \quad (6)$$

BCSE (7)–(11) were based on the Hanai principle, corrected for BMI that was used as a readily available measure to evaluate body composition. Parameters such as $\rho_{ECW}$, $\rho_{ICW}$, $K_B$ and density (D) of XE were combined into two parameters $K_{ECW}$ and $K_{ICW}$. $K_{ECW}$ and $K_{ICW}$ were always changing with BMI, unlike XE in which $K_{ECW}$ was constant. $\Delta TBW_{BCSE}$ was total body fluid volume change estimated by BCSE during HD with ultrafiltration according to equation (12). $TBW_{BCS\text{-}pre}$ and $TBW_{BCS\text{-}post}$ were TBW calculated by BCSE before and after dialysis with BMI at different times, respectively.

$$ECW_{BCSE} = k_{ECW}\left(\frac{H^2 \times \sqrt{Wt}}{R_e}\right)^{2/3} \quad (7)$$

$$ICW_{BCSE} = k_{ICW}\left(\frac{H^2 \cdot \sqrt{Wt}}{R_i}\right)^{2/3} \quad (8)$$

$$k_{ECW} = \frac{0.188}{BMI} + 0.2883 \quad (9)$$

$$k_{ICW} = \frac{5.8758}{BMI} + 0.4194 \quad (10)$$

$$TBW_{BCSE} = ECW_{BCSE} + ICW_{BCSE} \quad (11)$$

$$\Delta TBW_{BCSE} = TBW_{BCSE-pre} - TBW_{BCSE-post} \quad (12)$$

Equations (13)–(16) were HE [4] using $R_{50}$ and $X_{50}$. $H$ was the body height (centimeter) and Wt was the body weight (kilogram). $\Delta TBW_{HE}$ was body fluid volume change estimated by HE during HD with ultrafiltration according to equation (16). $TBW_{HE\text{-}pre}$ and $TBW_{HE\text{-}post}$ were TBW calculated by HE before and after dialysis, respectively.

$$ECW_{HE} = 0.0119\frac{H^2}{X_{50}} + 0.123\frac{H^2}{X_{50}} + 6.15 \quad (13)$$

$$TBW_{HE} = 0.446\frac{H^2}{X_{50}} + 0.126\,Wt + 5.82 \quad (14)$$

$$ICW_{HE} = TBW_{HE} - ECW_{HE} \quad (15)$$

$$\Delta TBW_{HE} = TBW_{HE-pre} - TBW_{HE-post} \quad (16)$$

Equation (17) was HS calculated according to Chamney *et al.* [12]. $M_{ExF}$ was the excess fluid of the body, $ECW_{WB}$ was mass of whole-body ECW, $ICW_{WB}$ was mass of whole-body ICW and $M_{WB}$ was body weight.

$$M_{EXF} = 1.136 \times ECW_{WB} - 0.430 \times ICW_{WB} - 0.114 \times M_{WB} \quad (17)$$

*Actual ultrafiltration volume*

Actual ultrafiltration volume (AUV) is based on the equation (18).

$$AUV = WT_{pre} - WT_{post} \quad (18)$$

where $WT_{pre}$ is weight before dialysis and $WT_{post}$ is weight after dialysis.

*Statistics*

Data were presented as mean ± SD. The Student's paired *t*-test was used to compare the $R_e$ and $R_i$ change during dialysis session. ECW, ICW and HS changes calculated using the same equation before and after dialysis were compared using paired *t*-test, respectively. And $P < 0.05$ was recognized as statistically significant (two sided). Analysis of variance (ANOVA) repeated measures analysis with Bonferroni correction (alpha < 0.0083) was used to compare the body fluid volume change by a different method. The validity of TBW change and HS change detected by bioimpedance method was based upon the evaluation of predicted values versus AUV values from weight by calculating the constant error [CE = AUV − predicted TBW or HS change (BIS)], *r* value (Pearson's correlation coefficient), standard error of the estimate (SEE) and total error $\left(TE = \sqrt{\sum(\text{predicted} - \text{actual})^2 / n}\right)$. The Bland–Altman method was used to identify the 95% limits of agreement between TBW change and AUV and HS change and AUV. Statistical analysis was performed with SPSS 11.0 (SPSS Inc., Chicago, IL).

## Results

### *Baseline characteristics of the patients*

Fifty stable HD patients (27 females) were studied during 114 measurements. The average age was 54.6 ± 13.9 years. They had been on HD for 63.4 ± 40.1 months. The mean height was 165.4 ± 8.8 cm. The causes of end stage renal disease were diabetes mellitus (6/50), hypertension (4/50), chronic glomerulonephritis (20/50) and others (20/50). Only seven patients had diabetes at the time of the study. The normal $Na^+$ dialysate was 138 mmol/L and there was no sodium or ultrafiltration profilling application used in all dialysis sessions.

### *Bioimpedance results and body fluid point estimation*

$R_e$, $R_{50}$, $X_{50}$ and $R_{inf}$ were significantly increased after dialysis sessions; however, dialysis induced no significant $R_i$ change (Table 1). The results of ECW, ICW, TBW and $M_{ExF}$ by different equations before and after dialysis are shown in Table 2. All bioimpedance equations detected significant ECW and $M_{ExF}$ decreased (Table 2). On the other hand, ICW calculated by BCSE did not change during dialysis with ultrafiltration; however, there was a significant increase of ICW calculated by XE and a significant decrease calculated by HE after dialysis with ultrafiltration (Table 2).

### *Total body fluid volume change results*

TBW and HS changes calculated by different equations and AUV during dialysis session are shown in Tables 3 and Table 4. Compared to AUV by ANOVA repeated measures, ΔTBW_XE was significantly lower than AUV (1.76 ± 0.89 versus 2.46 ± 0.89 L, $P < 0.0083$) and ΔTBW_HE was significantly higher than AUV (4.16 ± 1.36 versus 2.46 ± 0.89 L, $P < 0.0083$); however, ΔTBW_BCSE was close to AUV (2.27 ± 0.90 versus 2.46 ± 0.89 L, $P = 0.129$). TBW change validity results produced similar values for three methods compared to AUV. TE of ΔTBW_BCSE (0.85 L) was lower than ΔTBW_XE (1.15 L) and ΔTBW_HE (1.93 L). On the other hand, compared to AUV by ANOVA repeated measures, HS change detected by XE was significantly higher than AUV (2.75 ± 1.04 versus 2.46 ± 0.89 L, $P < 0.0083$); however, HS change detected by BCSE was similar to AUV (2.41 ± 0.86 versus 2.46 ± 0.89 L, $P = 1.0$) and HS change detected by HE was significantly higher than AUV (3.11 ± 1.11 versus 2.46 ± 0.89 L, $P < 0.0083$). HS change validity results produced similar results. TE of

**Table 1.** Values of impedance datas before and after dialysis session[a]

| | $R_e$ (Ω) | $R_i$ (Ω) | $R_{50}$ (Ω) | $X_{50}$ (Ω) | $R_{inf}$ (Ω) |
|---|---|---|---|---|---|
| Pre-HD | 605.75 ± 105.36 | 1775.79 ± 441.49 | 534.48 ± 96.06 | 44.61 ± 9.99 | 449.13 ± 81.34 |
| Post-HD | 763.70 ± 140.72 | 1772.90 ± 450.05 | 638.96 ± 119.94 | 63.40 ± 14.75 | 529.66 ± 99.57 |
| P-value | <0.01 | 0.74 | <0.01 | <0.01 | <0.01 |

[a]impedance values in pre- and post-HD were compared by paired *t*-test

**Table 2.** Comparison body fluid volume change using the same equation[a]

| | XE | BCSE | SFBIA |
|---|---|---|---|
| ECW (L) | | | |
| Pre-HD | 15.82 ± 3.90* | 15.47 ± 3.61** | 20.46 ± 3.54*** |
| Post-HD | 13.40 ± 3.36 | 13.13 ± 3.14 | 17.15 ± 2.86 |
| ICW (L) | | | |
| Pre-HD | 15.51 ± 5.07† | 17.47 ± 4.35†† | 17.40 ± 5.13††† |
| Post-HD | 16.17 ± 5.34 | 17.54 ± 4.36 | 16.55 ± 4.71 |
| TBW (L) | | | |
| Pre-HD | 31.33 ± 8.68§ | 32.94 ± 7.71§§ | 37.86 ± 8.17§§§ |
| Post-HD | 29.57 ± 8.41 | 30.67 ± 7.23 | 33.70 ± 7.07 |
| $M_{ExF}$ (L) | | | |
| Pre-HD | 3.93 ± 1.78# | 2.69 ± 1.51## | 8.38 ± 3.12### |
| Post-HD | 1.18 ± 1.68 | 0.28 ± 1.39 | 5.28 ± 2.60 |

[a]Comparing pre-HD and post-HD ECW,
*P < 0.01 using XE,
**P < 0.01 using BCSE,
***P < 0.01 using HE; comparing pre-HD and post-HD ICW,
†P < 0.01 using XE,
††NS using BCSE,
†††P < 0.01 using HE; comparing pre-HD and post-HD TBW,
§P < 0.01 using XE,
§§P < 0.01 using BCSE,
§§§P < 0.01 using HE; comparing pre-HD and post-HD $M_{ExF}$,
#P < 0.01 using XE,
##P < 0.01 using BCSE,
###P < 0.01 using HE.

ΔHS_BCSE (0.73 L) was lower than ΔHS_XE (0.93 L) and ΔHS_HE (1.17 L).

The Bland–Altman plot of TBW change is shown in Figure 1. The bias between ΔTBW_XE and AUV was −0.69 L and 95% limits of agreement was −2.50 to 1.12 L. Bias between ΔTBW_BCSE and AUV was −0.18 L and 95% limits of agreement was −1.81 to 1.44 L. Bias between ΔTBW_HE and AUV was 1.69 L and 95% limits of agreement was −0.08 to 3.48 L. The agreement between ΔTBW_BCSE and AUV was better than the other two methods. Figure 2 shows the agreement between HS change and AUV. The bias between ΔHS_XE and AUV was −0.30 L and 95% limits of agreement was −2.03 to 1.43 L. Bias between ΔHS_BCSE and AUV was −0.04 L and 95% limits of agreement was −1.40 to 1.47 L. Bias between ΔHS_HE and AUV was −0.65 L and 95% limits of agreement was −2.56 to 1.26 L. The agreement between ΔHS_BCSE and AUV was superior to the other two methods.

## Discussion

Our current study found that ICW, TBW and HS changes detected by BCSE were close to the corresponding actual change. The accuracy of BCSE was superior to XE and HE in body fluid volume point estimation in MHD patients.

SFBIA measures only at one frequency and a 50 KHz current will not penetrate completely into the cells so that the apparent resistivity is a mixture of ECW and ICW resistivity. TBW and ECW had to be determined empirically by comparison to dilution methods in SFBIA. Therefore, BIA equations may be applicable to the specific population but are likely to fail in individuals from a different population. For this reason, Hanai's [8] mixture conductivity theory and equivalent electrical circuit were applied to measure both ECW and ICW [13]. This may partly explain why TE of D_HE and HSD_HE (Tables 3 and 4) were the largest one.

However, even when the Hanai's mixture conductivity theory was implemented in XE, the TE of ΔTBW_XE and ΔHS_XE were larger than BCSE'S. XE assumes fixed resistivity (39 Ωcm for female and 40.5 Ωcm for male) [9], a fixed body density and a fixed shape factor $K_B$ in ECW calculation. However, different people may have a different shape factor and resistivity. From the literature, different constants were proposed, for example, in the work of Van Loan *et al.* [13], $\rho_{ECW}$ is found to be 40.3 Ωcm for male and 42.3 Ωcm for female. On the other hand, different body densities according to BMI group was reported in Shafer

**Table 3.** The validation results of TBW change by different equations during dialysis session[a]

| | WT | XE | BCSE | HE |
|---|---|---|---|---|
| $TBW_{pre}$ (L)- | 64.66 ± 15.26 | 31.33 ± 8.68 | 32.94 ± 7.71 | 38.04 ± 8.17 |
| $TBW_{post}$ (L) | 62.20 ± 14.99 | 29.57 ± 8.41 | 30.67 ± 7.23 | 33.86 ± 7.23 |
| ΔTBW (L) | 2.46 ± 0.89 | 1.76 ± 0.89* | 2.27 ± 0.90 | 4.16 ± 1.36* |
| Slope | | 0.46 | 0.563 | 0.49 |
| Intercept | | 1.65 | 1.175 | 0.42 |
| *R* | | 0.46 | 0.57 | 0.75 |
| SEE | | 0.79 | 0.73 | 0.59 |
| TE (L) | | 1.15 | 0.85 | 1.93 |
| Agreement | | | | |
| CE/bias ± 2 SD (L) | | −0.69 ± 1.85 | −0.18 ± 1.66 | 1.69 ± 1.82 |
| Lower (L) | | −2.54 | −1.84 | −0.13 |
| Upper (L) | | 1.16 | 1.48 | 3.51 |

[a]Different impedance methods were compared to AUV by ANOVA repeated measures.
*P < 0.0083.

**Table 4.** The validation results of HS change by different equations during dialysis session[a]

| | WT | XE | BCSE | HE |
|---|---|---|---|---|
| $TBW_{pre}$ (L)- | 64.66 ± 15.26 | 3.93 ± 1.78 | 2.69 ± 1.51 | 8.38 ± 3.12 |
| $TBW_{post}$ (L)- | 62.20 ± 14.99 | 1.18 ± 1.68 | 0.28 ± 1.39 | 5.28 ± 2.60 |
| ΔTBW (L) | 2.46 ± 0.89 | 2.75 ± 1.04* | 2.41 ± 0.86 | 3.11 ± 1.11* |
| Slope | | 0.51 | 0.67 | 0.44 |
| Intercept | | 1.06 | 0.83 | 1.1 |
| R | | 0.59 | 0.65 | 0.55 |
| SEE | | 0.72 | 0.68 | 0.75 |
| TE (L) | | 0.93 | 0.73 | 1.17 |
| Agreement | | | | |
| CE/bias ± 2 SD (L) | | −0.30 ± 1.76 | −0.04 ± 1.46 | −0.65 ± 1.94 |
| Lower (L) | | −2.03 | −1.40 | −2.56 |
| Upper (L) | | 1.43 | 1.47 | 1.26 |

[a]Different impedance methods were compared to AUV by ANOVA repeated measures.
*P < 0.0083.

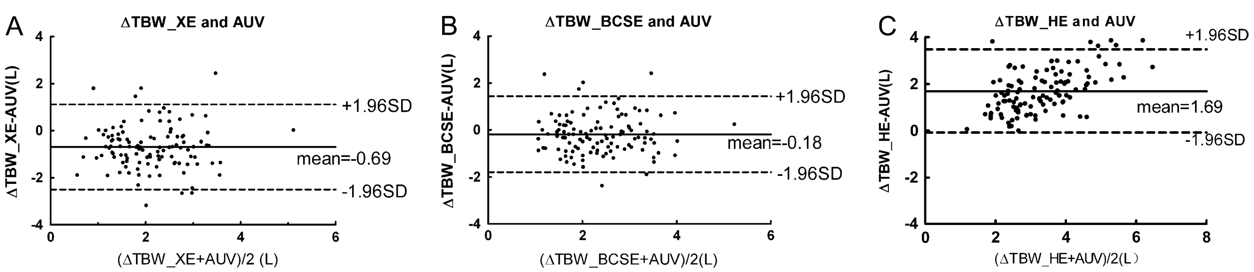


**Fig. 1.** Bland–Altman plot between TBW changes by different equations and AUV in dialysis session. (**A**) TBW change detected by XE versus AUV, (**B**) TBW change detected by BCSE versus AUV and (**C**) TBW change detected by HE versus AUV.

*et al.* [14] (normal 1.0487 ± 0.0187, overweight 1.0304 ± 0.0201 and obese 1.0121 ± 0.0137) by air displacement plethysmography. Another possible explanation could be that a fixed body shape factor $K_B$ of 4.3 was not an accurate assumption for extreme BMI subjects. $K_B$ ranged from 3.5 to 6.5 in Cox-Reijven *et al.* [15]. So individualizing resistivity and body density was reasonable.

Which indicator could be used as a correction surrogate? From the literature, the error for predicting TBW and ECW was correlated with BMI (correlation coefficients: ECW, −0.4721; TBW, −0.4607) [15]. The calculated $K_{ECW}$ also correlated with BMI ($r = -0.352$) [15]. The extracellular resistance and absolute point estimation of TBW and ECW was influenced by BMI [16, 17]. So introducing BMI to individualize resistivity was reasonable. BMI was introduced to the BCSE [11], and the agreement and TE using BCSE between TBW and HS change and AUV was better than the other two methods in this study. Comparing to standard Hanai approach, Moissl *et al.* [11] also found that BCSE equations improved SEE for ICW and TBW by 0.6 L (24%) for all subjects and by 1.2 L (48%) for 24 subjects with extreme BMIs (<20 and >30). First of all, the hydration constants of lean and fat tissue was different. Chamney *et al.* found that the hydration fraction (HF) of

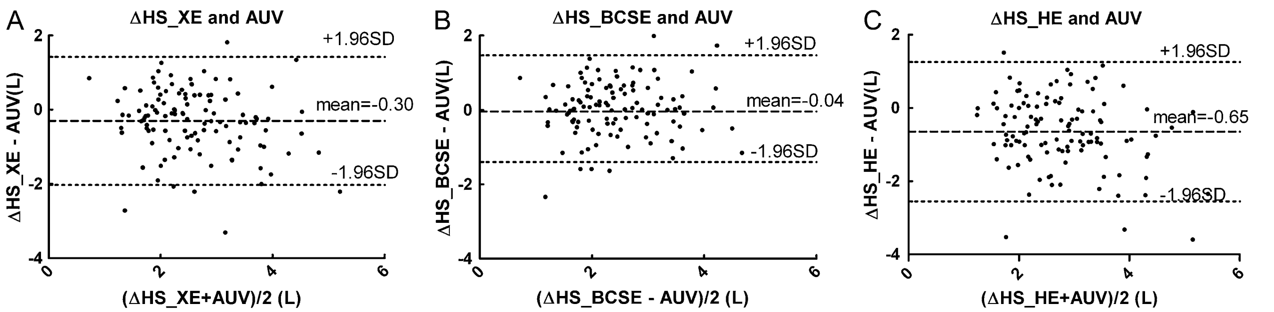


**Fig. 2.** Bland–Altman plot between HS changes by different equations and AUV in dialysis session. (**A**) HS change detected by XE versus AUV, (**B**) HS change detected by BCSE versus AUV, (**C**) HS change detected by HE versus AUV.

normally hydrated lean tissue ($NH_{LT}$) mass was 0.703 ± 0.009 with an ECW component of 0.266 ± 0.007. The HF of normally hydrated adipose tissue ($NH_{AT}$) mass was 0.197 ± 0.042 with an ECW component of 0.127 ± 0.015 [12]. Afterward, the apparent resistivity of intracellular volume may depend on the amount of lipids in fat cells, which is known to change significantly in states of overweight and obesity [18].

Another difference between XE and BCSE is that BCSE does not differ between males and females because tissue hydration constants might be independent of gender. The other reason maybe the fact that BCSE were derived using both a healthy population and a group of dialyzed patients, while XE and HE were derived from a healthy population.

According to the literature, a 4-h dialysis session with 138 mmol/L $Na^+$ dialysate without salt profile should not induce ICW change [19]. We found that there was no significant ICW change calculated by BCSE during ultrafiltration. However, ICW calculated by XE increased and HE decreased along with the fluid removal. Except the above-mentioned explanations, this may partly be explained by the fact that XE assuming ICW is a function of ECW, $\rho_{ECW}$, $\rho_{ICW}$, $\rho_{TBW}$, $R_e$, $R_i$. $\rho_{TBW}$ and $(R_e + R_i)/R_i$ will increase along with the fluid removal. The change could cause ICW change. ICW calculated by HE decreased along with the fluid removal.

In conclusion, the results of this study indicate that BCSE provided a better point estimation of ICW and TBW. BCSE may be useful as a field method for monitoring body fluid volume changes in MHD patients. And further work need to be done to improve the bioimpedance point estimation method.

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*Conflict of interest statement*. None declared.

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