Body water balance in hemodialysis patients reflects nutritional, circulatory, and body fluid status

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Abstract The ratio of the volumes of extracellular water to total body water (ECW/TBW) obtained by multi-frequency bioelectrical impedance analysis (MF-BIA) indicates body water balance. However, the characteristics of ECW/TBW in hemodialysis (HD) patients have not been fully investigated yet. We evaluated correlations of ECW/TBW with body composition, circulatory and body fluid status, and nutritional status in 60 stable maintenance HD patients using MF-BIA. ECW/TBW increased with increasing age and showed significant positive correlations with volume index (VI), cardiothoracic ratio, and brain natriuretic peptide, all of which are indices of circulatory and body fluid status. Furthermore, there were significant negative correlations between ECW/TBW and serum albumin (Alb), the geriatric nutritional risk index, and the normalized protein catabolic rate, all of which indicate nutritional status. Following multiple regression analysis, the independently related factors for total subjects were age, VI, and Alb. In obese HD patients, ECW/TBW tended to decrease, indicating intravascular dehydration. In conclusion, ECW/TBW in HD patients was shown to increase with age and can reflect circulatory, body fluid, and nutritional status, as well as the difference between predetermined dry weight and “optimal body weight” which may change along with a patient’s nutritional status.

Keywords aging, circulatory and body fluid status, hemodialysis (HD), multi-frequency bioelectrical impedance analysis (MF-BIA), nutritional status, ratio of extracellular water to total body water volume (ECW/TBW)

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Background

Bioelectrical impedance analysis (BIA) is used to evaluate biorheological properties including hemorheological factors [1, 2]. Recently, BIA has been used for evaluating dry weight (DW) [3–7] which is related to hemodynamics in hemodialysis (HD) patients. However, some issues still remain regarding BIA use for estimating DW [8].

Multi-frequency BIA (MF-BIA) enables the estimation of the ratio of extracellular water (ECW) to total body water (TBW) volume (ECW/TBW), on the basis of the electrical currents measured at a low frequency for ECW and high frequency for TBW [9–12]. In healthy adults, the distributions of TBW and ECW volumes are regulated within a narrow range [13] and reflect extracellular edema levels. The ratio of TBW to body weight decreases with increasing age in healthy adults; thus, ECW/TBW increases with increasing age [14, 15]. Furthermore, in healthy subjects, ECW/TBW increased with increasing percentages of fat mass (FM) to body weight (%FM), i.e. degree of obesity [16].

In patients with renal failure, ECW/TBW could be a useful index for estimating i) the DW of HD patients [5, 6] and ii) renal failure prognosis in patients with chronic kidney diseases [17]. Lopot et al. reported that the correlation between age and ECW/TBW, obtained by measuring MF-BIA in healthy subjects, was useful for estimating DW in HD patients [15]. However, only a few studies are available on the characteristics of ECW/TBW in HD patients [18, 19].

To our best knowledge, there are no previous studies on ECW/TBW of HD patients focusing on circulatory and nutritional indices as well as body composition. Therefore, we sought to evaluate the characteristics of ECW/TBW in
terms of i) body composition, ii) circulatory and body fluid status, and iii) nutritional status.

Methods

Subjects

We retrospectively evaluated 60 stable maintenance HD outpatients (30 males and 30 females) who were undergoing three HD sessions per week. Each patient underwent i) a body composition analysis by MF-BIA (InBody®S20; InBody Japan Inc., Tokyo, Japan) and ii) measurement of relative change in circulating blood volume (%BV) during HD in order to evaluate body fluid status. The ages of the subjects ranged from 43 to 90 years (67.7 ± 10.4 years), and HD duration was 12.5 ± 9.7 years. Underlying diseases included chronic glomerulonephritis, diabetic nephropathy, polycystic kidney disease, nephrosclerosis, rapidly progressive glomerulonephritis, IgA nephropathy, pyelonephritis, and other diseases (Table 1). Here, we excluded i) inpatients, ii) patients with HD duration < 3 months, iii) patients who discontinued HD because of complications, and iv) patients who had liver function abnormalities.

The present study was approved by the ethics committee of the Kurashiki Central Hospital, Okayama Japan (approval number: 1923), which waived the need for informed consent.

Measurement of body composition by MF-BIA

Body mass index (BMI), FM, %FM, intracellular water (ICW), ECW, and TBW were measured with the subjects in the supine position 10 min after each HD session. ECW/TBW was calculated from the obtained data, and fat-free mass (FFM) was calculated as the difference between body weight and FM.

Measurement of indices of circulatory and body fluid status

%BV during HD was measured by a continuous hematocrit monitor CRIT-LINE® (Fresenius Medical Care, Bad Homburg, Germany) in the same HD session in which the body composition analysis was performed. Continuous measurement of %BV was initiated 5 min after HD onset with a sensor attached to the arterial chamber located before a hemodialyzer. Volume index (VI), calculated from %BV as shown in Eq. 1, was used as an index of circulatory and body fluid status and the level of plasma refilling, and VI > –0.22 was used as a criterion for excessive body fluid status [20].

\[
\text{Volume Index (VI) } \left( [\%/(\text{hr})/(\text{mL/hr/kg})] \right) = \left( \frac{\%BV}{\text{HD time (hr)}} \right) / \left( \frac{\text{UF volume (mL)}}{\text{HD time (hr)}} / \text{post-HD body weight (kg)} \right)
\]

Here, UF stands for ultrafiltration.

Indices of body fluid and nutritional status

As additional indices of body fluid status, the post-HD x-ray cardiothoracic ratio (CTR) and brain natriuretic peptide (BNP) were measured by regular laboratory and physiological tests during the same month as the evaluation of the circulatory and other body fluid status. Nutritional status indices, including pre-HD and post-HD serum albumin (Alb) as well as pre-HD total cholesterol (T-cho) were measured, and we calculated the geriatric nutritional risk index (GNRI) [21] from pre-HD Alb and normalized protein catabolic rate (nPCR). We also measured C-reactive protein (CRP), an inflammatory marker related to nutritional status [22]. Alb, GNRI, nPCR, T-cho, and CRP were routinely measured on the same day.

Data analyses

Correlations between ECW/TBW and i) age, ii) body composition (height, body weight, BMI, FM, and %FM), iii) indices of circulatory and body fluid status (%BV, VI, S-BP, D-BP, CTR, and BNP) as well as nutritional status (Alb, GNRI, nPCR, and T-cho), and iv) CRP were investi-

| Underlying diseases | Number of subjects |
|---------------------|--------------------|
| Chronic glomerulonephritis | 7 (n = 30) 10 |  |
| Diabetic nephropathy | 11 4 | |
| Polycystic kidney disease | 3 4 | |
| Nephrosclerosis | 2 3 | |
| Rapidly progressive glomerulonephritis | 2 2 | |
| IgA nephropathy | 2 2 | |
| Pyelonephritis | 1 2 | |
| Other diseases | 2 3 | |

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| Other diseases | 2 3 | |

| Number of subjects |
|--------------------|
| All subjects (n = 60) | Male subjects (n = 30) | Female subjects (n = 30) |
| VI > –0.22 [(%/hr)/(mL/hr/kg)] | 13 6 7 | |
| VI ≤ –0.22 [(%/hr)/(mL/hr/kg)] | 47 24 23 | |
| DM | 15 11 4 | |
| Antihypertensive medication | 29 15 14 | |

VI: volume index, DM: diabetes mellitus
gated in total subjects. In addition, we examined gender-specific characteristics of ECW/TBW. We selected six independent factors: 1) sex, 2) presence of diabetes mellitus (DM), 3) age, 4) BMI as a measure of physical body composition, 5) VI as an index of circulatory and body fluid status, and 6) post-HD Alb as an index of nutritional status, and attempted to find the factors related to ECW/TBW in all HD patients.

Statistical analyses

All statistical analyses were performed using PASW Statistics 17.0 (SPSS, Chicago, USA). A linear regression analysis was applied to the correlations between ECW/TBW and the other measurement data, and the Student’s t-test was used to compare data between male and female subjects. In addition, a multiple regression analysis using a stepwise method was applied to the six factors (sex, presence of DM, age, BMI, VI, and post-HD Alb) to determine their relationship to ECW/TBW in total subjects. All data were presented as means ± SDs, and p < 0.05 was considered statistically significant.

Results

Body compositions and indices of circulatory, body fluid and nutritional status

Body composition and indices of circulatory, body fluid, and nutritional status for male, female, and total subjects are summarized in Table 3. There were no significant differences in age, HD duration, UF volume, UF rate, TBW, ECW/TBW, BMI, and FM between male and female subjects. In addition, a multiple regression analysis using a stepwise method was applied to the six factors (sex, presence of DM, age, BMI, VI, and post-HD Alb) to determine their relationship to ECW/TBW in total subjects. All data were presented as means ± SDs, and p < 0.05 was considered statistically significant.

Table 3: Body composition and indices of circulatory, body fluid, and nutritional status

| Measurement data          | All subjects (n = 60) | Male subjects (n = 30) | Female subjects (n = 30) |
|---------------------------|----------------------|-----------------------|--------------------------|
| Age [years]               | 67.7 ± 10.4          | 67.2 ± 10.9           | 68.1 ± 10.0              |
| HD duration [years]       | 12.5 ± 9.7           | 11.9 ± 10.4           | 13.1 ± 9.2               |
| Height [cm]               | 159.8 ± 8.9          | 166.2 ± 10.9**        | 153.1 ± 6.9**            |
| Body weight [kg] (pre-HD) | 55.2 ± 10.8          | 60.1 ± 10.3**         | 50.2 ± 9.0**             |
| Body weight [kg] (post-HD)| 53.2 ± 10.5          | 58.0 ± 10.0**         | 48.4 ± 8.8**             |
| UF volume [L]             | 2.0 ± 0.7            | 2.1 ± 0.8             | 1.9 ± 0.6                |
| UF rate [%]               | 3.6 ± 1.1            | 3.5 ± 1.2             | 3.7 ± 1.0                |
| ICW [L]                   | 17.1 ± 3.6           | 19.5 ± 3.2**          | 14.7 ± 2.1**             |
| ECW [L]                   | 11.2 ± 2.1           | 12.7 ± 1.7**          | 9.7 ± 1.3**              |
| TBW [L]                   | 28.3 ± 5.7           | 32.2 ± 4.8            | 24.4 ± 3.4               |
| ECW/TBW [-]               | 0.39783 ± 0.01175    | 0.39627 ± 0.01244     | 0.39939 ± 0.01099        |
| BMI [kg/m²]               | 20.8 ± 3.5           | 20.9 ± 3.0            | 20.7 ± 4.0               |
| FM [kg]                   | 14.9 ± 7.3           | 14.5 ± 6.4            | 15.3 ± 8.2               |
| %FM [%]                   | 27.2 ± 10.7          | 24.2 ± 9.1*           | 30.3 ± 11.5*             |
| %BV [%]                   | –10.4 ± 4.55         | –9.83 ± 4.23          | –11.15 ± 4.83            |
| VI [(%/hr)/(mL/hr/kg)]    | –0.29 ± 0.10         | –0.28 ± 0.11          | –0.29 ± 0.10             |
| S-BP [mmHg] (pre-HD)      | 137.8 ± 24.2         | 139.7 ± 27.0          | 136.0 ± 21.4             |
| D-BP [mmHg] (pre-HD)      | 74.0 ± 16.1          | 74.1 ± 15.6           | 73.8 ± 16.9              |
| Heart rate [beat/min] (pre-HD) | 81.6 ± 13.3        | 82.1 ± 15.9           | 81.1 ± 10.2              |
| S-BP [mmHg] (post-HD)     | 136.3 ± 26.1         | 137.7 ± 27.0          | 134.9 ± 25.5             |
| D-BP [mmHg] (post-HD)     | 71.7 ± 13.2          | 71.1 ± 12.0           | 72.3 ± 14.5              |
| Heart rate [beat/min] (post-HD) | 75.9 ± 14.5        | 75.2 ± 17.8           | 76.5 ± 10.7              |
| CTR [%]                   | 49.6 ± 5.4           | 48.4 ± 4.4            | 50.7 ± 6.2               |
| BNP [pg/mL] (post-HD)     | 407.0 ± 674.8        | 504.2 ± 858.2         | 313.2 ± 427.5            |
| Alb [g/dL] (pre-HD)       | 3.4 ± 0.4            | 3.4 ± 0.4             | 3.5 ± 0.3                |
| Alb [g/dL] (post-HD)      | 3.8 ± 0.5            | 3.8 ± 0.6             | 3.8 ± 0.4                |
| GNRi [-]                  | 89.9 ± 9.0           | 89.2 ± 9.2            | 90.7 ± 9.0               |
| nPCR [g/kg/day]           | 0.84 ± 0.14          | 0.81 ± 0.12           | 0.87 ± 0.16              |
| T-cho [mg/dL] (pre-HD)    | 158.3 ± 31.0         | 153.3 ± 34.3          | 163.2 ± 26.9             |
| CRP [mg/dL] (pre-HD)      | 0.66 ± 0.17          | 0.96 ± 2.30           | 0.36 ± 0.55              |

Male subjects vs. Female subjects, *: p < 0.05, **: p < 0.001
HD: hemodialysis, UF: ultrafiltration, ICW: intracellular water, ECW: extracellular water, TBW: total body water, ECW/TBW: ratio of extracellular to total body water, BMI: body mass index, FM: fat mass, %FM: percentage of fat mass to body weight, %BV: percent change of circulating blood volume, VI: volume index, S-BP: systolic blood pressure, D-BP: diastolic blood pressure, CTR: cardiothoracic ratio, BNP: brain natriuretic peptide, Alb: serum albumin, GNRI: geriatric nutritional risk index, nPCR: normalized protein catabolic rate, T-cho: total cholesterol, and CRP: C-reactive protein
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Significant correlations between ECW/TBW and age were observed for total subjects, male subjects, and female subjects. However, there were no significant correlations between ECW/TBW and height. There were significant negative correlations between ECW/TBW and body weight, BMI, FM, or %FM in total subjects and male subjects, but not in female subjects (Table 4).

When compared between lean (%FM ≤ 15%; 6 male and 5 female subjects) and obese (%FM ≥ 30%; 11 male and 15 female subjects), ECW/TBW tended to be lower in the obese group than in the lean group for both male and female subjects (0.40821 ± 0.01148 vs. 0.39458 ± 0.01074, respectively, for male subjects; p < 0.05; 0.40365 ± 0.01692 vs. 0.39993 ± 0.01028, respectively, for female subjects; p = 0.662). VI was significantly lower in the obese group (–0.17 ± 0.09 vs. –0.32 ± 0.06, for male subjects; p < 0.01; –0.20 ± 0.09 vs. –0.34 ± 0.09, for female subjects; p < 0.05; Fig. 2).

Relative factors of ECW/TBW examined by multiple regression analysis

Table 5 shows the results of the multiple regression analysis using the stepwise method with ECW/TBW as the objective variable and six variables of interest (sex, DM, age, BMI, VI, and post-HD Alb) as explanatory variables. Independent relative factors related to ECW/TBW, in total subjects, were age, VI, and post-HD Alb, but not sex, DM, or BMI.

Discussion

We observed the significant correlations between ECW/TBW measured by MF-BIA and the various indices of circulatory, body fluid, and nutritional status in HD patients.

Relationship between ECW/TBW and age

ECW/TBW increased with increasing age in both male and female subjects, whereas no significant correlation was observed between ECW/TBW and HD duration. Lopot et al. also reported that ECW/TBW increased with increasing age in both healthy subjects and HD patients [15]; our result showed the same trend. The correlation equation between ECW/TBW and age for total subjects was ECW/TBW = 0.00061 × age + 0.35631 (r = 0.543, p < 0.001). Here, our results differed from Lopot’s results [ECW/TBW = 0.00066 × age + 0.4052 (r = 0.35)]. Some potential reasons for this difference might include i) the differences in the body water balance of HD patients between the two studies and ii) the different types of measurement equipment and electrodes that were used [15]. It is also conceivable that the intercept of the correlation equation between ECW/TBW and age would be higher when patients with excessive body fluid are included. In this study, the percentage of the subjects with VI > –0.22 (an index for an excessive body fluid volume) was relatively small (21.6%).

The ratio of the ECW to ICW (ECW/ICW) in healthy subjects increased with increasing age [23]. In cases of FFM hydration, ICW/FFM decreased and ECW/FFM increased with increasing age [14]; however, TBW/FFM was nearly constant at 73% in healthy adults [24]. In this study, we confirmed that the relative changes in ICW/FFM, ECW/FFM, and TBW/FFM, observed with increasing age of HD patients who were evaluated after HD, showed similar trends to those observed in healthy subjects. We also observed that the correlation between ECW/TBW and age improved in the subjects with VI ≤ –0.22 without any subjects with excessive body fluid volume (data not shown). Since multiple regression analysis also showed that age is an independent relative factor of ECW/TBW, the relative increase in ECW/TBW with increasing age may reflect the physiological characteristics of human body composition, common to both healthy subjects and HD patients.
Table 4  Linear regression analyses between ECW/TBW and body composition, indices of circulatory, body fluid, or nutritional status

| Measurement data          | All subjects (n = 60) | Male subjects (n = 30) | Female subjects (n = 30) |
|---------------------------|-----------------------|------------------------|--------------------------|
|                           | Correlation coefficient | p-value | Correlation coefficient | p-value | Correlation coefficient | p-value |
| Age [years]               | 0.543                 | <0.001                | 0.432                     | <0.05     | 0.678                  | <0.001  |
| HD duration [years]       | 0.176                 | 0.179                  | 0.266                     | 0.156     | 0.046                  | 0.809   |
| Height [cm]               | −0.321                | <0.05                  | −0.360                    | 0.051     | −0.342                 | 0.064   |
| Body weight [kg] (pre-HD) | −0.552                | <0.001                 | −0.724                    | <0.001    | −0.340                 | 0.066   |
| Body weight [kg] (post-HD)| −0.539                | <0.001                 | −0.724                    | <0.001    | −0.311                 | 0.095   |
| UF volume [L]             | −0.431                | <0.001                 | −0.321                    | 0.084     | −0.566                 | <0.01   |
| UF rate [%]               | −0.157                | 0.232                  | −0.013                    | 0.946     | −0.371                 | <0.05   |
| ICW [L]                   | −0.476                | <0.001                 | −0.582                    | <0.001    | −0.441                 | <0.05   |
| ECW [L]                   | −0.253                | 0.051                  | −0.285                    | 0.127     | −0.140                 | 0.461   |
| TBW [L]                   | −0.396                | <0.01                  | −0.484                    | <0.01     | −0.332                 | 0.073   |
| BMI [kg/m²]               | −0.395                | <0.01                  | −0.688                    | <0.001    | −0.157                 | 0.409   |
| %FM [%]                   | −0.344                | <0.01                  | −0.610                    | <0.001    | −0.141                 | 0.457   |
| %BV [%]                   | 0.503                 | <0.001                 | 0.554                     | <0.01     | 0.521                  | <0.01   |
| VI [(%/hr)/(mL/hr/kg)]    | 0.462                 | <0.001                 | 0.650                     | <0.001    | 0.380                  | <0.05   |
| S-BP [mmHg] (pre-HD)      | −0.033                | 0.806                  | −0.061                    | 0.749     | 0.032                  | 0.866   |
| D-BP [mmHg] (pre-HD)      | −0.107                | 0.417                  | −0.235                    | 0.211     | 0.027                  | 0.888   |
| S-BP [mmHg] (post-HD)     | 0.327                 | <0.05                  | 0.336                     | 0.069     | 0.339                  | 0.067   |
| D-BP [mmHg] (post-HD)     | 0.105                 | 0.423                  | 0.082                     | 0.668     | 0.120                  | 0.527   |
| CTR [%]                   | 0.409                 | <0.01                  | 0.418                     | <0.05     | 0.381                  | <0.05   |
| BNP [pg/mL] (post-HD)     | 0.443                 | <0.001                 | 0.434                     | <0.05     | 0.595                  | <0.001  |
| Alb [g/dL] (pre-HD)       | −0.467                | <0.001                 | −0.502                    | <0.01     | −0.474                 | <0.01   |
| Alb [g/dL] (post-HD)      | −0.702                | <0.001                 | −0.717                    | <0.001    | −0.714                 | <0.001  |
| GNRI [-]                  | −0.575                | <0.001                 | −0.773                    | <0.001    | −0.388                 | <0.05   |
| nPCR [g/kg/day]           | −0.438                | <0.001                 | −0.379                    | <0.05     | −0.582                 | <0.001  |
| T-cho [mg/dL] (pre-HD)    | −0.242                | 0.062                  | −0.442                    | <0.05     | −0.022                 | 0.908   |
| CRP [mg/dL] (pre-HD)      | 0.170                 | 0.197                  | 0.214                     | 0.265     | 0.292                  | 0.118   |

Fig. 1  Relationships between ECW/TBW and age; a: All subjects, b: Male subjects, c: Female subjects.
Fig. 2 ECW/TBW and VI in lean and obese HD patients; a: Male subjects, b: Female subjects. *: p < 0.05, **: p < 0.01. Box indicates the 25th–75th percentile range (inter quartile range: IQR), and the line in each box shows median. Error bars indicate the range of 25th percentile – 1.5 × IQR and 75th percentile + 1.5 × IQR. Open circles indicate out-of-range data.

Fig. 3 Relationships between ECW/TBW and indices of circulatory or body fluid status; a: All subjects, b: Male subjects, c: Female subjects.
In both male and female subjects, ECW/TBW decreased with increasing height and body weight, and this trend was more significant in male subjects than in female subjects. However, in multiple regression analysis, BMI was not independently related to ECW/TBW in total subjects, and thus, physical body composition may have minor effects on ECW/TBW as a whole.

Muscle mass shows a more significant declining trend with increasing age in males than in females [25]. ICW fluctuations seem to indicate that muscle mass causes variations in ECW/TBW. In fact, the standard deviation of the ICW in male subjects was significantly larger than in female subjects (p < 0.05, Table 3). Consequently, variation in the physical body composition and the muscle masses in male subjects might affect the correlation between ECW/TBW and age. On the other hand, it was reported that the higher level of ECW/TBW with diabetic HD patients compared with other HD patients [19]. DM might affect ECW/TBW in male subjects because of the higher DM incidence in male subjects than in female subjects (Table 2). However, examining total subjects together, DM did not significantly affect ECW/TBW. Further research on the relationships between ECW/TBW and DM is needed.

**Table 5** Multiple regression analysis for the factors affecting ECW/TBW (stepwise method)

| Explanatory variables | Partial regression coefficient (B) | Standard error (SE B) | Standardized partial regression coefficient (β) |
|-----------------------|-----------------------------------|-----------------------|-----------------------------------------------|
| Sex                   | —                                 | —                     | —                                             |
| DM                    | —                                 | —                     | —                                             |
| Age [years]           | 0.000468                          | 0.000113              | 0.414**                                        |
| BMI [kg/m²]           | —                                 | —                     | —                                             |
| VI [f(%/hr)/(mL/hr/kg)]| 0.0482                            | 0.0105                | 0.419**                                        |
| Alb [g/dL] (post-HD)  | −0.0082                           | 0.0032                | −0.260*                                         |

Multiple coefficient of determination (R^2) 0.515**

*: p < 0.05, **: p < 0.001

**Relationships between ECW/TBW and body composition**

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In the previous body composition model study, an increase of ECW/TBW in healthy subjects with increasing %FM was reported [16]; however, the results of the HD patients in our study indicated the opposite trend. ECW/TBW of HD patients with high %FM (obese) tended to be lower than that of HD patients with low %FM (lean), and VI was also significantly lower in the high %FM HD patients. Accordingly, it is presumed that ECW/TBW tends to decrease and plasma refilling attenuates, i.e. intravascular dehydration, markedly during HD in obese HD patients. This may be because of the fact that ECW/TBW is strongly related to the indices of circulatory, body fluid, and nutritional status in HD patients.

To determine the DW of HD patients, some DW evaluation indices, such as edema or clinical symptoms, BP, CTR, inferior vena cava diameter, and atrial natriuretic peptide have been collectively used in daily clinical practice [34]. However, daily evaluation of DW using these indices is impractical. Consequently, it is difficult to reflect the changes of body water balance on the DW evaluation on a real time basis. Therefore, the predetermined DW does not always agree with “optimal body weight,” i.e. body weight with optimal fluid distribution. If “optimal body weight” decreases due to nutritional status deteriorations, the gap between “optimal body weight” and predetermined DW would widen, leading to an increase in ECW/TBW. In addition, age-related deterioration in nutritional status may also cause ECW/TBW to rise [19]. In contrast, adequate nutritional status may lead to increases in “optimal body weight” owing to the rise in FM and %FM. Further decreases in ECW due to the narrowing gap between “optimal body weight” and the predetermined DW may decrease ECW/TBW. Furthermore, since the ECW decreases in contrast with increasing FM in obese HD patients, the rate of ultrafiltration volume to ECW is thus higher than that of lean HD patients with the same body weight, leading to intravascular dehydration. Therefore, in HD patients with severe obesity, great attention should be paid to declining blood pressure during HD due to intravascular dehydration. In clinical practice, ECW/TBW should be maintained at a higher level in obese HD patients. Further research on the relevance between ECW/TBW and %FM is still necessary.

Consequently, HD patients’ ECW/TBW may fluctuate, essentially reflecting the altered gap between “optimal body weight” and the predetermined DW because of a change in “optimal body weight” due to shifting nutritional status. If the predetermined DW does not agree with “optimal body weight,” the characteristics of ECW/TBW of HD patients may differ from that of healthy subjects. As long as the body water balance of HD patients is maintained at the same level as healthy subjects, ECW/TBW of HD patients should exhibit characteristics similar to healthy subjects.
Limitations

Our small sample size and the difference of physical body composition between male and female subjects might have influenced the results of the multiple and linear regression analysis. In addition, we were unable to perform simultaneous laboratory blood testing along with ECW/TBW and VI measurements. Thus, body weight and nutritional status may have varied according to measurement times. In the current study, we did not focus on the underlying diseases, complications, or DW status in order to focus on the characteristics of ECW/TBW in HD patients. Thus, the optimal range of ECW/TBW for HD patients as well as any possible influences of diseases including cardiac dysfunctions on ECW/TBW remains unclear. In addition, since stable HD outpatients were selected as subjects in this study, we did not investigate the possible effects of three-space fluid volume, such as the pleural fluid and ascites fluid, on ECW/TBW. Characterization of ECW/TBW in HD patients, including the relationship with underlying diseases and body fluid status, requires additional investigations.

Conclusions

In HD patients, ECW/TBW (an index of body water balance), measured by MF-BIA, increases with age and can reflect circulatory, body fluid, and nutritional status. In obese HD patients, ECW/TBW tends to decrease, indicating intravascular dehydration. The characteristics of ECW/TBW of HD patients may differ from those of healthy subjects, reflecting the difference between the predetermined DW and "optimal body weight," which may change along with the nutritional status.

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Conflict of Interests The authors declare that they have no conflicts of interests related to this study.

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