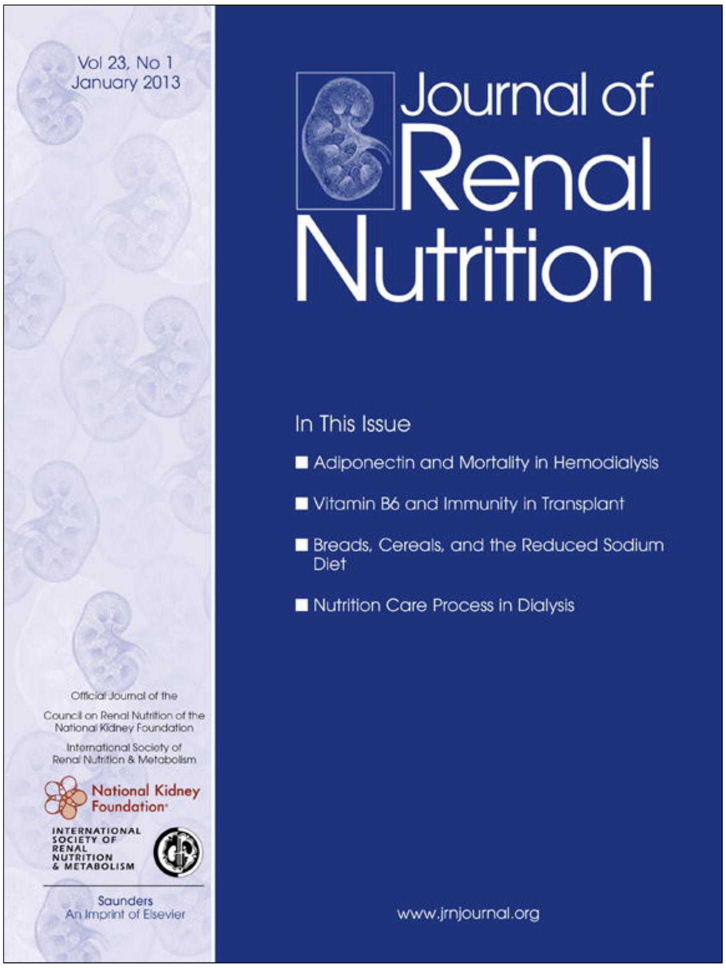
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RESEARCH BRIEF

Assessment of Body Composition Using Dry Mass Index and Ratio of Total Body Water to Estimated Volume Based on Bioelectrical Impedance Analysis in Chronic Kidney Disease Patients

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Objective: Body mass index (BMI) is commonly used for assessment of nutritional status. However, changes in BMI in chronic kidney disease (CKD) patients are affected not only by muscle and fat but also by fluid volume. The ratio of extracellular water (ECW_{BIA}) to total body water (TBW_{BIA}) in multifrequency bioelectrical impedance analysis is commonly used for assessing abnormal fluid status. This study reexamines ECW_{BIA}/TBW_{BIA} and evaluates the reliability of TBW_{BIA}/TBW_{watson} and dry mass index (DMI) in the assessment of fluid and nutritional status.

Design, Setting, and Subjects: TBW_{BIA}, intracellular water (ICW_{BIA}), and ECW_{BIA} were measured in 45 randomly selected CKD patients. Participants were surveyed for age, gender, BMI, blood pressure, serum albumin, estimated glomerular filtration rate, and proteinuria. DMI was calculated by the formula ([weight − TBW_{BIA}]/height^2) and TBW_{BIA}/TBW_{watson} using an anthropometric formula (Watson). Fluid and nutritional status were assessed using ECW_{BIA}/TBW_{BIA}, TBW_{BIA}/TBW_{watson}, and DMI.

Results: TBW_{BIA}/TBW_{watson} positively correlated with weight, BMI, and diastolic blood pressure and negatively correlated with age and serum albumin level. In contrast, ECW_{BIA}/TBW_{BIA} correlated with ICW deficit, aging, and body weight loss. On the basis of DMI and TBW_{BIA}/TBW_{watson}, participants were categorized as follows: 1 obese patient with hypovolemia and 2 with euvolemia; 17 overweight patients with hypovolemia (n = 6), euvolemia (n = 8), or hypervolemia (n = 3); 24 patients of optimal weight with hypovolemia (n = 10), euvolemia (n = 9), or hypervolemia (n = 5); and 1 underweight patient with euvolemia.

Conclusions: A combination of DMI, BMI, and TBW_{BIA}/TBW_{watson} makes it possible to include assessment of fluid volume to the physique index. In addition, ECW_{BIA}/TBW_{BIA} is not a reliable marker of edematous state in CKD patients.

ADEQUATE ASSESSMENT OF fluid and nutritional status is of major importance in monitoring chronic kidney disease (CKD) patients. The isotopic dilution technique (D_2O) and dual-energy X-ray absorptiometry (DEXA) are considered reliable for total body water (TBW) measurement.[1] However, they are problematic in terms of invasiveness and convenience. Multifrequency bioelectrical impedance analysis (MF-BIA) is an alternative to D_2O and DEXA.[2] MF-BIA, which is able to distinguish between intra- and extracellular components, has been proposed for the assessment of fluid and nutritional status in CKD patients.[3,4] Anthropometric formulas with tracer dilution techniques (e.g., Watson) have been widely used to calculate TBW_{watson} in CKD patients.[5] These formulas

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provide information about adequate fluid volume balance because they have been originally derived from pooled data of healthy volunteers. Although these formulas are routinely used when calculating dialysis efficiency, they do not measure fluid volume.

The ratio of extracellular water (ECW_{BIA}) to TBW_{BIA} in MF-BIA is commonly used for assessing abnormal fluid status. Based on the assumption that the normal ratio of intracellular water (ICW_{BIA}) to ECW_{BIA} is 62:38, the ECW_{BIA}/TBW_{BIA} ratio is classified as follows: ECW-deficit state: $ECW_{BIA}/TBW_{BIA} < 0.360$; optimal ECW state: $ECW_{BIA}/TBW_{BIA} = 0.360$ to 0.389; mild ECW excess state: $ECW_{BIA}/TBW_{BIA} = 0.390$ to 0.399; and edematous state: $ECW_{BIA}/TBW_{BIA} \geq 0.400$ (Biospace Co. Ltd., Seoul, Korea; www.biospaceamerica.com). This assumption is based on the concept that excess ECW results in edema.[6] The latent connotation is that ICW is substantially unaffected by changes in fluid volume. However, it is unclear whether the ECW_{BIA}/TBW_{BIA} ratio can accurately determine an edematous state.[4] The suitability of MF-BIA as an assessment method needs to be established.[7,8] Alternatively, the TBW_{BIA}/TBW_{watson} ratio, which can be calculated using anthropometric formulas, may be useful for assessing fluid volume because TBW_{BIA} provides the value of fluid volume and TBW_{watson} provides the adequacy of fluid volume.

Body mass index (BMI) and lean body mass (LBM), which can be calculated using the formula ($TBW_{BIA}/0.733$) in MF-BIA, are commonly used for accessing nutritional status.[9,10] However, BMI and LBM are affected by fluctuations in fluid status in response to fluid volume and are undesirable for nutritional assessment. In such conditions, the dry mass index (DMI), which subtracts TBW_{BIA} from body weight, is more appropriate.

The aim of the present study is to reexamine fluid volume status by calculating the ECW_{BIA}/TBW_{BIA} ratio, and to evaluate the practicality of the TBW_{BIA}/TBW_{watson} ratio and DMI in assessment of nutritional status.

Materials and Methods

Study Design

A total of 45 ambulatory CKD patients were randomly selected from our kidney center to participate in this study. Informed consent was obtained from all patients. This study was approved by the Ethics Committee of Toho University Omori Medical Center, Tokyo, Japan. CKD was defined as any of the following: estimated glomerular filtration rate (eGFR) of 60 mL/min/1.73 m^2 for at least 3 months; presence of proteinuria (spot urine/protein ratio of 300 mg/g creatinine); or the presence of structural kidney disease (e.g., adult polycystic kidney disease), according to the

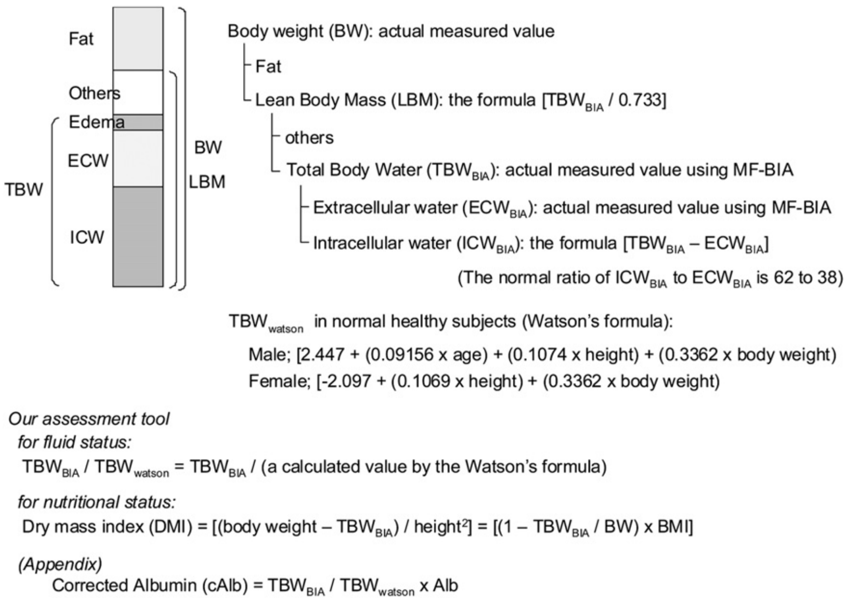

Figure 1. Frame format of the body fluid composition, our assessment tools, and equations.

Table 1. Baseline Clinical Characteristics of Participants

Patients	Male	Female	*P*
Number (n)	35	10	
Age (years)	68.7 ± 11.3	68.4 ± 12.5	n.s.
Height (m)	1.64 ± 0.05	1.51 ± 0.06	<.01
BW (kg)	66.0 ± 10.7	54.7 ± 6.5	<.01
BMI (kg/m^2)	24.5 ± 3.6	24.1 ± 2.1	n.s.
Underlying diseases			
Diabetes mellitus (n [%])	15 (42.9%)	3 (30.0%)	n.s.
Nephrosclerosis (n [%])	9 (25.7%)	2 (20.0%)	
Glomerulonephritis (n [%])	5 (14.3%)	3 (30.0%)	
Unknown (n [%])	6 (17.1%)	2 (20.0%)	
Clinical findings			
eGFR (mL/min/1.73 m^2)	27.2 ± 16.1	22.7 ± 18.8	n.s.
Proteinuria (g/gCr)	1.48 ± 1.98	3.57 ± 4.39	n.s.
Alb (g/dL)	3.7 ± 0.5	3.9 ± 0.5	n.s.
Ht (%)	36.3 ± 5.8	33.1 ± 5.2	n.s.
Systolic BP (mmHg)	133.2 ± 18.3	154.2 ± 28.9	n.s.
Diastolic BP (mmHg)	79.3 ± 9.7	81.1 ± 12.5	n.s.
Body fluid composition			
TBW_{BIA} (L [% of BW])	35.5 ± 5.6 (54.0 ± 4.0)	26.5 ± 3.7 (48.4 ± 2.6)	<.01
ICW_{BIA} (L [% of BW])	21.4 ± 3.6 (32.5 ± 2.6)	15.9 ± 2.4 (28.9 ± 1.6)	<.01
ECW_{BIA} (L [% of BW])	14.1 ± 2.1 (21.5 ± 1.6)	10.6 ± 1.3 (19.4 ± 1.2)	<.01
LBM (kg [% of BW])	48.5 ± 7.6 (73.6 ± 5.4)	36.1 ± 5.0 (66.0 ± 3.6)	<.01
ECW_{BIA}/TBW_{BIA}	0.398 ± 0.011	0.401 ± 0.011	n.s.
Estimated volume by the Watson formula			
TBW_{Watson} (L [% of BW])	35.7 ± 4.4 (54.5 ± 3.0)	27.5 ± 2.1 (50.5 ± 2.5)	<.01
Modified values in this study			
TBW_{BIA}/TBW_{Watson}	0.992 ± 0.062	0.959 ± 0.062	n.s.
DMI (kg/m^2)	11.3 ± 2.2	12.5 ± 1.5	n.s.

Alb, albumin; BMI, body mass index; BP, blood pressure; BW, body weight; DMI, dry mass index; ECW, extracellular water; eGFR, estimated glomerular filtration rate; Ht, hematocrit; ICW, intracellular water; LBM, lean body mass; TBW, total body water.

Values are expressed as mean ± SD or percentage.

Kidney Disease Outcomes Quality Initiative and the position statement of Kidney Disease: Improving Global Outcomes.[11] The participants were surveyed for age, gender, height, body weight, BMI, underlying disease, blood pressure, serum albumin (Alb), hematocrit, eGFR, and proteinuria.

Table 2. Clinical Characteristics as Per Classification of the ECW_{BIA}/TBW_{BIA} Ratio

	ECW_{BIA}/TBW_{BIA}			
Patients	0.360–0.389	0.390–0.399	≥0.400	*P*
Number (n)	8	12	25	
Age (years)	60.1 ± 10.1	65.1 ± 6.8	73.1 ± 11.7*	<.01
Male/female	6/2	10/2	19/6	n.s.
Clinical findings				
BW (kg)	65.0 ± 9.9	73.2 ± 9.6	58.4 ± 8.7†	<.01
BMI (kg/m^2)	25.6 ± 2.7	27.1 ± 2.9	22.7 ± 2.6*,†	<.01
eGFR (mL/min/1.73 m^2)	31.1 ± 17.4	35.2 ± 18.5	20.3 ± 13.3†	<.05
Proteinuria (g/gCr)	1.9 ± 3.4	1.4 ± 1.4	2.2 ± 3.1	n.s.
Alb (g/dL)	4.0 ± 0.5	4.0 ± 0.4	3.6 ± 0.6	n.s.
Ht (%)	38.4 ± 5.2	38.5 ± 5.3	33.3 ± 5.3*,†	<.01
Systolic BP (mmHg)	131.1 ± 16.5	133.8 ± 21.0	140.4 ± 24.0	n.s.
Diastolic BP (mmHg)	81.7 ± 10.9	79.1 ± 7.4	79.3 ± 11.3	n.s.

Values are expressed as mean ± SD. Analysis of variance was used to compare the differences between groups.

**P* < .05, compared with each category of ECW/TBW = 0.360–0.389.

†*P* < .05 compared with each category of ECW/TBW = 0.390–0.399.

eGFR was calculated using the revised formula of $(194 \times Cr^{-1.094} \times Age^{-0.287})$ ($\times 0.739$ for females) for Japanese patients according to the Modified Diet in Renal Disease method.[12]

To assess the components of body fluid composition, we used the assessment methods and equations described below (Fig. 1).

BIA was performed in the standard manner with the patient lying in the supine position on a flat nonconductive bed for at least 15 minutes. For determination of TBW_{BIA}, we used a segmental MF-BIA instrument (Inbody S20, Biospace Co. Ltd., Seoul, Korea; www.biospaceamerica.com), which has 8 tactile electrodes. The microprocessor-controlled switches and impedance analyzer were activated, and segmental resistances of right arm, left arm, trunk, right leg, and left leg were measured at 4 frequencies (5, 50, 250, and 500 kHz). Thus, a set of 20 segmental resistances was measured for each individual. With these data, TBW_{BIA} was calculated from the sum of the measurements for each body segment using MF-BIA software.

TBW_{watson} was calculated according to the Watson formula.[5] BMI was classified as follows: underweight: < 18.5; optimal weight: 18.5 to 24.9; overweight: 25.0 to 29.9; obese: >30.0 (kg/m^2).[6] The ECW_{BIA}/TBW_{BIA} ratio was classified according to the mentioned criteria. We also evaluated the correlation between the components of body fluid and the TBW_{BIA}/TBW_{Watson} ratio. $TBW_{BIA}/TBW_{watson} < 0.970$ indicated hypovolemia; $TBW_{BIA}/TBW_{watson} = 0.970$ to 1.029 indicated euvolemia; and $TBW_{BIA}/TBW_{watson} \geq 1.030$ indicated hypervolemia in this study. The relationship between the value of the difference between TBW_{BIA} and TBW_{watson} and the value of the TBW_{BIA}/TBW_{watson} ratio was evaluated to assess the validity of the range of ±3%. Finally, we compared the corrected Alb (cAlb), which was calculated using the TBW_{BIA}/TBW_{watson} ratio, with Alb. The values of cAlb and Alb were divided into 2 groups according to the following reference value: lower limit 3.8 (g/dL) in Alb.

Statistical Analyses

Measured values were expressed as means ± SD, and the Mann–Whitney *U* test, Fisher exact test, and χ^2 test were used for statistical analysis to compare 2 independent groups. Either 1-way analysis of variance or the Bonferroni test was used for statistical analysis on more than 2 independent groups. The significance of correlation was analyzed using Spearman rank correlation coefficient. A *P* value < .05 was considered statistically significant.

Results

Baseline Characteristics of Participants

Relevant baseline characteristics of the 45 study participants, the body fluid composition obtained by MF-BIA and anthropometric formula, and modified values are shown in Table 1. The average TBW_{BIA} value for males was 54.0 ± 4.0%, and that for females was 48.4 ± 2.6%. The average values of TBW_{BIA} were lower than those of

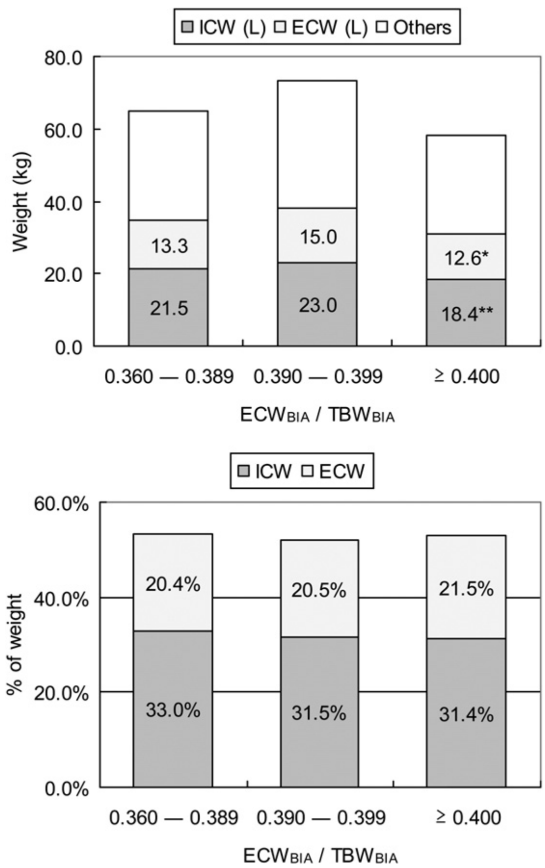

Figure 2. Body composition as per classification of the extracellular water in bioelectrical impedance analysis/total body water in bioelectrical impedance analysis (ECW_{BIA}/TBW_{BIA}) ratio. *P, **P < .01, compared with each category of ECW/TBW = 0.390–0.399.

TBW_{watson}. The values of the ECW_{BIA}/TBW_{BIA} ratio indicated a mild ECW excess state in most males and an edematous state in most females in the study. In contrast, the values of the TBW_{BIA}/TBW_{watson} ratio were <1, indicating a fluid volume deficit.

ECW_{BIA}/TBW_{BIA} Ratio

For the ECW_{BIA}/TBW_{BIA} ratio, data were compared between optimal ECW, mild ECW excess, and edematous groups (Table 2). The participants in the edematous group were significantly older and had lower body weight, eGFR, and hematocrit than those in the other 2 groups. With regard to body fluid composition, this group showed a significant decrease in ICW_{BIA} and ECW_{BIA} compared with the mild ECW excess group. In contrast, the ECW_{BIA}/body weight ratio increased with an increase in the ECW_{BIA}/TBW_{BIA} ratio. With these results, increase in the ECW_{BIA}/TBW_{BIA} ratio indicated higher ICW_{BIA} deficit than the decrease in ECW_{BIA} with higher age and body weight loss, but not with an ECW_{BIA} excess (Fig. 2).

TBW_{BIA}/TBW_{watson} Ratio: The Watson Formula

In contrast to the EBW_{BIA}/TBW_{BIA} ratio, the hypervolemic group was significantly younger and had higher diastolic blood pressure and lower Alb levels than the hypovolemic group (Table 3). As the TBW_{BIA}/TBW_{watson} ratio increased, the ratio of ECW_{BIA} and ICW_{BIA} to body weight also increased. Despite no significant difference in body weight between the euvolemic and hypervolemic groups, changes in proportion were particularly evident between these groups (Fig. 3).

To set up the criterion value of the TBW_{BIA}/TBW_{watson} ratios, the correlation equation between the absolute value of ($TBW_{BIA} - TBW_{watson}$) and the TBW_{BIA}/TBW_{watson} ratio was determined. According to the correlation equation ($[TBW_{BIA} - TBW_{watson}] = 33.074 \times [TBW_{BIA}/TBW_{watson}] - 32.94$), an increase or decrease of 3% indicated a change of about ±1.0 L in this study.

Assessment of Fluid Volume and Nutritional Status Using DMI and the TBW_{BIA}/TBW_{watson} Ratio

The relationship between DMI and BMI is shown for male and female participants in Figure 4. The formula indicating this relationship is ($DMI = 0.633 \times BMI - 4.198$) for males and ($DMI = 0.6737 \times BMI - 4.004$) for females. Based on this formula, DMI values for males and females were 7.5, 11.6, and 14.8, and 8.5, 12.8, and 16.2 (kg/m^2), respectively, corresponding to 18.5, 25, and 30 (kg/m^2) for BMI, respectively. Although most participants were included in the same range for both DMI and BMI, a few participants were not. These participants should have been categorized as overweight and obese based on the amount of muscle and body fat, they but were categorized in the downward range in BMI

Table 3. Clinical Characteristics as Per Classification of the TBW_{BIA}/TBW_{watson} Ratio Using the Watson Formula

Patients	TBW_{BIA}/TBW_{watson} <0.97	0.97–1.029	≥1.03	*P*
Number (n, [%])	17 (37.8%)	20 (44.4%)	8 (17.8%)	
Age (years)	68.7 ± 11.6	67.1 ± 8.9	60.8 ± 11.9*	<.01
Male/female	11/6	17/3	7/1	n.s.
Clinical findings				
BW (kg)	57.1 ± 8.5	67.4 ± 11.1*	67.5 ± 9.7*	<.01
BMI (kg/m^2)	23.2 ± 2.8	25.1 ± 3.8	25.1 ± 2.6	n.s.
eGFR ($mL/min/1.73\ m^2$)	25.5 ± 14.3	26.9 ± 16.2	26.2 ± 23.5	n.s.
Proteinuria (g/gCr)	1.19 ± 2.30	2.25 ± 3.00	2.76 ± 3.12	n.s.
Alb (g/dL)	3.9 ± 0.4	3.8 ± 0.4	3.4 ± 0.8*	n.s.
Ht (%)	35.4 ± 5.3	36.3 ± 5.8	34.4 ± 7.1	n.s.
Systolic BP (mmHg)	136.0 ± 27.8	135.1 ± 19.4	146.3 ± 15.0†	n.s.
Diastolic BP (mmHg)	76.1 ± 10.6	79.9 ± 9.2	86.7 ± 9.7*	<.05

Values are expressed as mean ± SD.

*$P < .05$, compared with each category of $TBW_{BIA}/TBW_{watson} < 0.97$.

†$P < .05$, compared with each category of $TBW_{BIA}/TBW_{watson} = 0.97–1.029$.

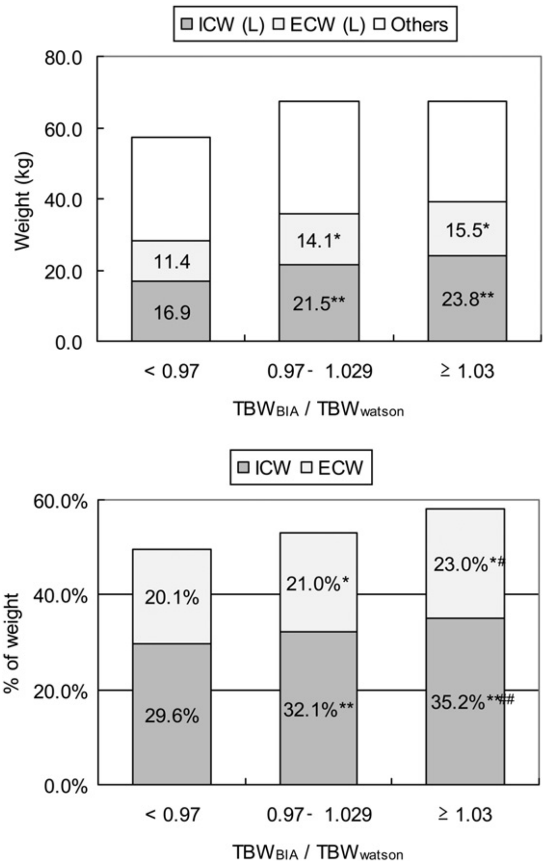

Figure 3. Body composition as per classification of the TBW_{BIA}/TBW_{watson} ratio using the Watson formula.
*P, **P < .01, compared with each category of TBW_{BIA}/TBW_{watson} < 0.97.
#P, ##P < .01, compared with each category of TBW_{BIA}/TBW_{watson} = 0.97–1.029.

because of the body weight loss associated with fluid volume decline. Patients with values to the right of the linear regression line were indicated to be hypervolemic, whereas those with values to the left were indicated to be hypovolemic.

The 3 fluid states (hypovolemic, euvolemic, and hypervolemic) can be distinguished by calculating the TBW_{BIA}/TBV_{watson} ratio. The results of fluid status examination according to the TBW_{BIA}/TBV_{watson} ratio were similar to the shifts in the relationship between DMI and BMI (Fig. 5). However, some patients had fluid disturbances despite being close to the linear regression line.

Based on DMI and TBW_{BIA}/TBV_{watson}, the participants were categorized as follows: 1 obese patient with hypovolemia and 2 with euvolemia; 17 overweight patients with hypovolemia (n = 6), euvolemia (n = 8), or hypervolemia (n = 3); 24 patients of optimal weight with hypovolemia (n = 10), euvolemia (n = 9), or hypervolemia (n = 5); and 1 underweight patient with euvolemia.

Corrected Albumin

The clinical characteristics and body composition categorized by cAlb and Alb are shown in Table 4 and Figure 6. Significant differences were found in body weight, BMI, DMI, and ICW in the group with cAlb ≥ 3.8, but no significant difference was evident in Alb.

Discussion

Congestive heart failure is one of the most frequent complications of CKD and is associated with poor clinical outcomes. The pathogenesis of heart failure is multifactorial. Chronic arterial hypertension, uremic cardiomyopathy, coronary disease, and valvular disease all lead to myocardial damage that may eventually result in congestive heart failure. The other contributory factors are

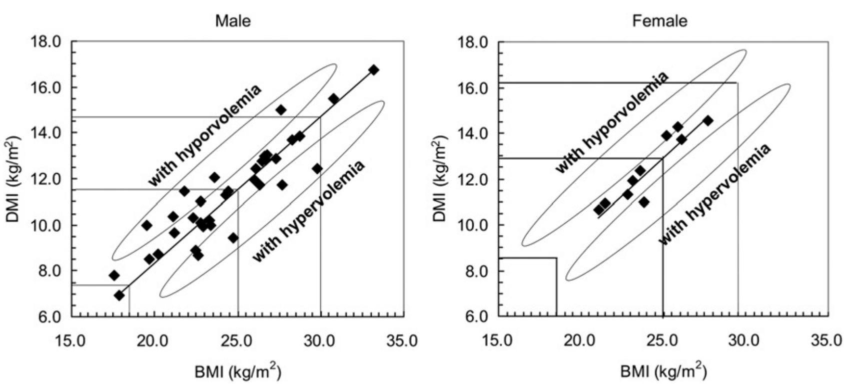

Figure 4. Comparison between dry mass index and body mass index.

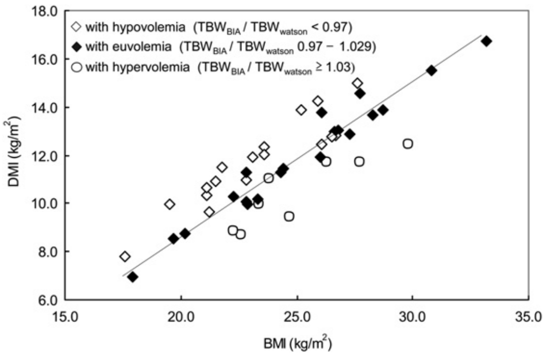

Figure 5. The relationship between the TBW_{BIA}/TBW_{watson} ratio and the shift in relationship between dry mass index and body mass index. Open diamonds: hypovolemia; black diamonds: euvolemia; open circles: hypervolemia.

chronic fluid volume overload, anemia, metabolic acidosis, secondary hyperparathyroidism, and malnutrition–inflammation complex syndrome. To alleviate these problems, adequate assessment of fluid and nutritional status is of major importance in monitoring CKD patients. However, to date, we still are exploring ways of adequately assessing fluid and nutritional status in these patients.

MF-BIA is useful for assessing fluid and nutritional status in a noninvasive, simple, and easily accessible manner. However, data of CKD patients who are hypovolemic or hypervolemic often appear to mislead many physicians for the following 3 reasons: (1) with aging and body weight loss, the ECW_{BIA}/TBW_{BIA} ratio is affected by ICW deficiency but not by ECW volume excess; (2) there are no clearly established values for the normal range of adequate fluid volume according to variations in body composition; and (3) the values of LBM and fat are usually derived from TBW.

Considering our results, the balance of ECW and ICW appears to change depending on the body type (endomorph and ectomorph) and edematous status (Fig. 7). The ECW/TBW and ECW/ICW ratios have been reported as strong predictors of patient survival.[13] It is possible that this result was affected not only by ECW excess but also by aging and body weight loss. Therefore, data obtained by MF-BIA should be amended in such a way as to avoid misinterpretation in both CKD patients and healthy individuals. The limitations of using the ECW/TBW ratio are clear. This is an important problem; it can be misleading when the ECW/TBW ratio is regarded as a marker of edematous state. Thus, the adequate reference range of the ECW/TBW ratio should be revised by considering age.

We assessed fluid volume status in CKD patients using the TBW_{BIA}/TBW_{watson} ratio calculated using the Watson formula adjusted for height, weight, age, and gender. Use of this ratio may diminish the impact of these factors on the measurement of fluid and nutritional status. The difference between TBW_{BIA} and TBW_{watson} indicates changes in TBW in terms of unbalanced fluid volume status. In this study, the range for the

Table 4. Clinical Characteristics as Per Corrected Albumin and Albumin

	Corrected Albumin		Albumin	
Patients	<3.8	≥3.8	<3.8	≥3.8
Number (n)	21	24	18	27
Age (years)	69.4 ± 12.5	68.0 ± 10.6	70.0 ± 12.8	67.8 ± 10.5
Male/female	17/4	18/6	14/3	20/7
Clinical findings				
BW (kg)	59.1 ± 8.8	67.3 ± 11.4*	60.3 ± 8.2	65.7 ± 12.1
BMI (kg/m²)	23.0 ± 3.2	25.6 ± 3.0*	23.4 ± 3.1	25.1 ± 3.3
DMI (kg/m²)	10.8 ± 2.1	12.3 ± 1.9*	10.9 ± 2.1	12.0 ± 2.0
eGFR (mL/min/1.73 m²)	18.2 ± 13.5	33.2 ± 16.1†	19.3 ± 14.2	30.9 ± 16.7§
Proteinuria (g/gCr)	2.8 ± 3.2	1.2 ± 2.1*	3.0 ± 3.4	1.2 ± 2.0‡
Ht (%)	32.9 ± 4.8	38.0 ± 5.6†	33.0 ± 4.6	37.3 ± 5.9‡
Systolic BP (mmHg)	143.9 ± 21.3	131.3 ± 21.6*	145.6 ± 21.3	131.6 ± 21.2‡
Diastolic BP (mmHg)	81.1 ± 10.3	78.4 ± 10.2	82.1 ± 10.7	78.0 ± 9.7

Values are expressed as mean ± SD.
*$P < .05$.
†$P < .01$, compared with each category of corrected albumin <3.8.
‡$P < .05$.
§$P < .01$, compared with each category of albumin <3.8.

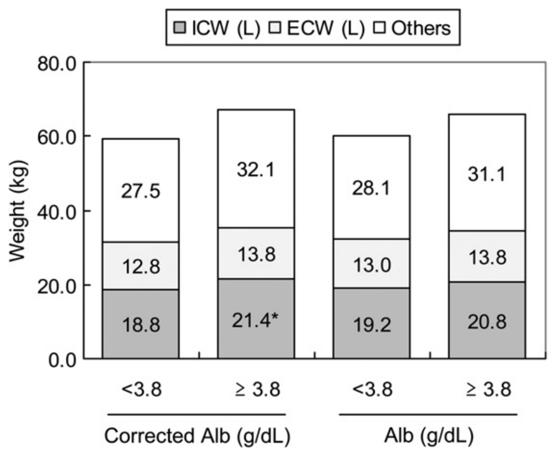

Figure 6. Body composition as per corrected albumin (first two colums); and albumin (second two colums). $^{*}P < .01$, compared with ICW of corrected albumin < 3.8.

euvolemic state determined by the TBW_{BIA}/TBW_{watson} ratio was 0.970 to 1.029. However, this assertion lacks satisfactory evidence at present. Moreover, interpretation of the TBW_{BIA}/TBW_{watson} ratio should be made with caution because of gender differences in standard deviation using the Watson formula (3.76 in males and 3.60 in females).[5] Although our results seem to explain clinical fluid volume status well, the reference range of the TBW_{BIA}/TBW_{watson} ratio should be further studied in catamnestic assessments.

We propose DMI rather than BMI be used during assessment of nutritional status in CKD patients. BMI has long been 1 of the most popular and acceptable nutritional markers. However, as body weight changes because of fluctuations in fluid status, BMI also changes and hence cannot be used as an accurate nutritional marker. DMI excludes the factor of fluid volume status and therefore is a more suitable nutritional marker. However, in this study, only a few patients fell into the difference range. Classification of BMI and DMI was too wide to assess changes in fluid volume. Therefore, the relationship between DMI and BMI is more important than these actual values. A shift in the relationship between DMI and BMI mainly indicates hypovolemia or hypervolemia. Although we were able to assess fluid volume status by analyzing the shift only, the TBW_{BIA}/TBW_{watson} ratio could provide a more accurate method for detecting the degree of hypovolemia or hypervolemia.

A combination of DMI, BMI, and TBW_{BIA}/TBW_{watson} makes it possible to include assessment of fluid volume status to the physique index. However, results for some patients were close to the linear regression line despite having fluid disturbance. If results of fluid volume status are corrected, results for these participants are plotted to the right or left; thus, they should deviate from the line. It was unclear which factor in our study caused these errors: the amount of composition in DMI, the measurement deviation of MF-BIA, or a random error in the Watson formula.

We showed that cAlb corrected the fluid volume factor. The results appeared consistent with clinical parameters, and increases and decreases in cAlb correlated with ICW. Body cell mass, which combines ICW and protein in MF-BIA, was reported as a malnutritional marker.[14] Body cell mass deterioration depends on ICW deficit. Thus, cAlb may be a potential nutritional marker. However, it is unclear whether the distribution of intravascular volume is equivalent to changes in TBW; there is no way to determine this in this study. Therefore, we suggest cAlb be used as a reference value in nutritional assessment.

Previous studies have reported indications and limitations of body composition analysis using MF-BIA.[15-18] Cooper et al. compared the results of TBW assessment in CKD patients by different methods such as D_2O, Watson formula, MF-BIA, and calculating TBW as 58% of body weight.[15] According to their report, the Watson formula significantly underestimated TBW. The mean TBW measured using MF-BIA did not differ significantly from the mean D_2O value, and the reliability of the results did not vary enormously. Woodrow et al.

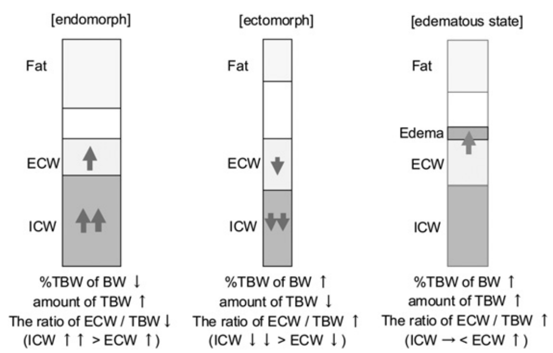

Figure 7. The balance of extracellular water and intracellular water depending on the body type (endomorph and ectomorph) and edematous status.

reported more errors with BIA than with D_2O and DEXA for TBW measurement in CKD patients.[17,18] In addition, Woodrow reported that the validity of BIA may be affected by age despite the fact that age itself is an important factor in MF-BIA.[19]

These uncertainties regarding MF-BIA were essentially similar to our findings. However, these reports have not completely denied the value of TBW assessment by MF-BIA. MF-BIA is still more accurate than anthropometric measurements and can be performed more simply, conveniently, and noninvasively than D_2O and DEXA. In this study, D_2O and DEXA were not assessed because of our focus on the benefits of MF-BIA for CKD patients; however, the mechanical accuracy of MF-BIA was not assessed, and D_2O and DEXA measurements were not clinically available. Moreover, it is not a contradiction that the Watson formula underestimated TBW in CKD patients with unbalanced fluid status. Our methods for assessing body composition partially resolve these problems. In conclusion, we suggest that the assessment of body composition using MF-BIA could be applied for practical use in CKD patients.

Practical Application

A combination of DMI and BMI could help in the assessment of body composition in case of changes in body weight. Moreover, the TBW_{BIA}/TBW_{watson} ratio can be used for assessing fluid volume status in CKD patients. These methods make it possible to include fluid volume status to the physique index. This information is useful to patients and those who provide them with nutritional guidance.

References

1. Woodrow G, Oldroyd B, Turney JH. Four-component model of body composition in chronic renal failure comprising dual-energy X-ray absorptiometry and measurement of total body water by deuterium oxide dilution. *Clin Sci (Lond).* 1996;91:763-769.

2. Cha K, Brown EF, Wilmore DW. A new bioelectrical impedance method for measurement of the erythrocyte sedimentation rate. *Physiol Meas.* 1994;15:499-508.

3. Bellizzi V, Scalfi L, Terracciano V, et al. Early changes in bioelectrical estimates of body composition in chronic kidney disease. *J Am Soc Nephrol*. 2006;17:1481-1487.

4. Woodrow G, Devine Y, Cullen M, Lindley E. Application of bioelectrical impedance to clinical assessment of body composition in peritoneal dialysis. *Perit Dial Int*. 2007;27:496-502.

5. Watson PE, Watson ID, Batt RD. Total body water volumes for adult males and females estimated from simple anthropometric measurements. *Am J Clin Nutr.* 1980;33:27-39.

6. McManus ML, Churchwell KB, Strange K. Regulation of cell volume in health and disease. *N Engl J Med*. 1995;333:1260-1266.

7. Chan C, McIntyre C, Smith D, et al. Combining near-subject absolute and relative measures of longitudinal hydration in hemodialysis. *Clin J Am Soc Nephrol*. 2009;4:1791-1798.

8. John B, Tan BK, Dainty S, et al. Plasma volume, albumin, and fluid status in peritoneal dialysis patients. *Clin J Am Soc Nephrol*. 2010;5:1463-1470.

9. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults. *WNJ.* 1998;97:20-21. 24-25,27-37.

10. Jaffrin MY. Body composition determination by bioimpedance: an update. *Curr Opin Clin Nutr Metab Care.* 2009;12:482-486.

11. Levey AS, Eckardt KU, Tsukamoto Y, et al. Definition and classification of chronic kidney disease: a position statement from kidney disease: improving global outcomes (KDIGO). *Kidney Int*. 2005;67:2089-2100.

12. Matsuo S, Imai E, Horio M, et al. Revised equations for estimated GFR from serum creatinine in Japan. *Am J Kidney Dis.* 2009;53:982-992.

13. Chen W, Guo LJ, Wang T. Extracellular water/intracellular water is a strong predictor of patient survival in incident peritoneal dialysis patients. *Blood Purif.* 2007;25:260-266.

14. Earthman C, Traughber D, Dobratz J, et al. Bioimpedance spectroscopy for clinical assessment of fluid distribution and body cell mass. *Nutr Clin Pract*. 2007;22:389-405.

15. Cooper BA, Aslani A, Ryan M, et al. Comparing different methods of assessing body composition in end-stage renal failure. *Kidney Int*. 2000;58:408-416.

16. Basile C, Vernaglione L, Bellizzi V, et al. Total body water in health and disease: have anthropometric equations any meaning? *Nephrol Dial Transplant*. 2008;23:1997-2002.

17. Woodrow G, Oldroyd B, Turney JH, Tompkins L, Brownjohn AM, Smith MA. Whole body and regional body composition in patients with chronic renal failure. *Nephrol Dial Transplant*. 1996;11:1613-1618.

18. Woodrow G, Oldroyd B, Turney JH, Davies PS, Day JM, Smith MA. Measurement of total body water by bioelectrical impedance in chronic renal failure. *Eur J Clin Nutr.* 1996;50:676-681.

19. Woodrow G. Body composition analysis techniques in the aged adult: indications and limitations. *Curr Opin Clin Nutr Metab Care.* 2009;12:8-14.