Estimate of Body Water Compartments and of Body Composition in Maintenance Hemodialysis Patients: Comparison of Single and Multifrequency Bioimpedance Analysis

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Objective: The goal of this study was to compare the adequacy of single and multifrequency bioimpedance analysis (BIA) to evaluate body water compartments, body composition, and nutritional status in maintenance hemodialysis patients.

Design: Cross-sectional study.

Setting: University-based hemodialysis unit.

Patients: Nineteen patients (12 male, 7 female), ages 28 to 82 years (mean, 58.9), treated with maintenance hemodialysis (MHD) for 0.5 to 15 years (mean, 7.3).

Intervention: This was a noninterventional study. Patients gave their informed consent to the diagnostic procedures performed.

Main outcome measures: Total body water (TBW), extracellular water (ECW), fat-free mass (FFM), and body cell mass (BCM) volumes were estimated with single-frequency (sf BIA) and multifrequency (mf BIA) plethysmographs before and after a midweek dialytic session. Predialysis TBW also was estimated from anthropometric data (e TBW). Serum albumin, prealbumin and myoglobin, and creatinine index were determined as indicators of nutritional status and muscle mass.

Results: Sf BIA and mf BIA gave very similar results for TBW volumes. A high linear correlation was also found between e TBW values and both sf TBW and mf TBW; however, a statistically significant difference was found between e TBW and sf and mf TBW. Sf BIA and mf BIA gave quite different results for ECW, particularly when measured predialysis. The results obtained for FFM indicate a poor agreement between sf and mf BIA. The agreement was better when FFM was measured postdialysis. The values of BCM, either measured predialysis or postdialysis, indicate a significant difference between sf and mf BIA. FFM and BCM estimated with mf BIA had a closer correlation with creatinine index than sf BIA. mf BCM had also a higher correlation with serum myoglobin, which is produced by muscle cells.

Conclusions: TBW can be estimated with enough confidence from either sf or mf BIA at any time. On the contrary, the results of ECW are significantly different with sf and mf BIA when measured predialysis. Thus, it seems more convenient to perform BIA after dialysis, in particular when assessing the "ideal" body weight. The measurements of FFM and BCM, obtained with either sf or mf BIA, are correlated with different indicators of nutritional status. In particular, mf BCM seems more appropriate than sf BCM for estimating muscle mass.

THE ASSESSMENT OF the nutritional status of chronic kidney disease patients plays a central role in nephrologic practice. In fact, renal insufficiency is probably an important risk factor for malnutrition in older adults, and nutritional status is a major determinant of the outcome of maintenance hemodialysis patients (MHD). In particular, in these patients malnutrition is closely related to morbidity and is a predictor of mortality.

In MHD patients, protein-energy malnutrition is frequent and is related to dialysis vintage, and can be caused by a decreased intake of nutrients, mainly proteins and calories; scarce appetite; or

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increased protein catabolism due to metabolic acidosis, hyperparathyroidism, insulin resistance, and inflammation. In any case, moderate to severe malnutrition induces a body weight loss and alterations in body composition, mainly a reduction in fat mass and in muscle mass and an increase in total body fluids (TBW), with a prevalent increase in extracellular water (ECW).

One essential point, still debated, is which methodology to choose for early identification and accurate evaluation of malnutrition in MHD patients. The Kidney Disease Outcomes and Quality Initiative (K/DOQI) guidelines 2000 reported that studies are needed to determine the most effective combination of measures of nutritional status for evaluating protein-energy malnutrition.[1] On the basis of a recent European consensus, nutritional status should be evaluated from clinical data, such as history of weight loss, body mass index, muscle mass, subcutaneous fat mass, and biochemical parameters, such as plasma albumin, and creatinine, bicarbonate, and cholesterol levels. Subjective global assessment is considered a well-validated tool for evaluating nutritional status, and dual-energy X-ray absorptiometry (DEXA) is a useful method for attaining a more detailed assessment of lean body mass. In any case, comorbid conditions should be assessed and C-reactive protein (CRP) measured as a marker of inflammation, because there is a close relationship between malnutrition on one side and comorbid conditions and inflammation on the other.[2] The current opinion is that the assessment of uremic malnutrition requires using multiple measurements concomitantly, with no definitive single method that can be considered as a gold standard.[3]

In addition to nutritional evaluation, the measurement of body fluid compartments is necessary to accomplish the maintenance of the equilibrium in body fluids, which is one of the major tasks of hemodialysis. Furthermore, the achievement of the "ideal" or "dry" body weight is crucial for an adequate control of arterial blood pressure. However, the assessment of ideal body weight in hemodialysis patients is still controversial. In particular, different methods have been proposed to evaluate TBW, ECW, and hence the achievement of ideal body weight.

The analysis of electrical body impedance (BIA) is a simple, objective, and inexpensive method of analyzing body composition and measuring body fluid volumes in normal subjects and in patients affected by different chronic diseases.[4–6] Thus, BIA should allow evaluating nutritional status and the equilibrium between body fluids compartments in MHD patients. BIA can be performed using single-frequency (sf) or multifrequency (mf) plethysmographs. The adequacy of sf BIA and mf BIA for the evaluation of body composition and of body fluids compartments is still debated. Finally, the usefulness of the measurements of fat-free mass (FFM) and of body cell mass (BCM) obtained by BIA as indicators of muscle mass in MHD patients still needs to be fully validated.

The primary goal of this study was to compare the adequacy of sf and mf BIA to evaluate body fluids compartments (TBW and ECW) and body mass composition (FFM and BCM). The usefulness of sf BIA and mf BIA for the evaluation of nutritional status in MHD patients will be compared.

Patients and Methods

Patients

Nineteen end-stage renal disease patients (12 male, 7 female), clinically stable, without signs of edema, treated with maintenance hemodialysis for 6 months to 15 years (mean, 7.3 years), ages 28 to 82 years (mean, 58.9 years), with a body height of 143 to 179 cm (mean, 165 cm), body weight of 48.9 to 99.3 kg (mean, 68.2 kg), and a body mass index of 17.9 of 35.6 (mean, 25.0) participated in this study. Seven patients were treated with bicarbonate hemodialysis; 12 were treated with hemodiafiltration. Patients were treated with a 3 dialysis/week schedule, 3 to 4 hours long for each session. All patients had null residual renal function and were totally anuric.

The study was conducted in accordance with the ethical guidelines proposed by the Declaration of Helsinki. All patients gave their informed consent.

Study Protocol

Patients were examined on the occasion of a midweek dialytic session and at the next session. Body weight, serum urea, and serum creatinine were measured immediately before the beginning of the two dialysis sessions and 30 minutes after the end of the first session. Serum proteins, albumin, prealbumin, myoglobin, and C-reactive protein were measured immediately before the

midweek session. BIA was performed immediately before both dialytic sessions and 30 minutes after the end of the midweek dialysis session.

Measurement of Body Height and Weight

Body height was measured at the nearest 0.5 cm using a standard stadiometer; weight was measured with an electronic bed scale at the nearest 0.1 kg.

Measurement of Electrical Body Impedance

Four electrodes were placed on the right hand and foot,[4] or on the side contralateral to the arteriovenous fistula, of supine patients, and whole-body BIA was measured with sf and mf plethysmographs. The measurements were performed immediately before the start and 30 minutes after the end of a midweek dialytic session, and immediately before the start of the next session, 2 days later.

Single-Frequency Impedance Analyzer

Resistance and reactance, which are the two vectors of impedance, were measured with an sf impedance analyzer (STA-BIA, Akern, Florence, Italy), using a low-amplitude alternate current at single frequency (0.8 mA, 50 KHz). It is generally acknowledged that resistance depends positively on fat content of the body and negatively from total body fluids. Reactance, which expresses the capacitance of the body, is positively dependent from the number of cell membranes. In addition to resistance and reactance values, this apparatus displays a value of BCM, estimated from these electrical data, without knowledge of the height and weight of the patients.

Multifrequency Impedance Analyzer

Total body electrical impedance to an alternate current (0.2 mA) with four different frequencies (5, 50, 100, and 200 KHertz) was measured using a multifrequency analyzer (Quadscan 4000, Bodystat, UK). It is generally acknowledged that impedance is low in the presence of a high amount of body fluids. In particular, impedance to the passage of a high-frequency current depends on total body fluids, whereas impedance to introduction of a low-frequency current depends only from extracellular fluids.

Total and Extracellular Body Water

Predialysis volume of TBW was estimated (e TBW) according to Chertow et al[7] from age, gender, height, predialysis weight, and diabetes status. In the same patients, predialysis and postdialysis values of TBW were obtained by means of the sf BIA (sf TBW) and by the mf BIA (mf TBW).

Because no formula is available for predicting ECW from anthropometric data, predialysis and postdialysis values of ECW volume were obtained only by means of BIA: sf ECW and mf ECW.

Fat-Free Mass and Body Cell Mass

Predialysis and postdialysis values of FFM and BCM volume were obtained by means of sf BIA (sf FFM and sf BCM) and mf BIA (mf FFM and mf BCM), using the different manufacturer equations that combine electric data with body weight and height of patients. An additional value of BCM (sf1 BCM) was directly obtained with sf BIA apparatus from electric measurements, without knowledge of the body weight and height of patients.

Clinical Chemistry Determinations

Serum creatinine and urea were measured using a standard autoanalyzer method (Crea Roche, Hitachi 917; Urea Roche, Hitachi 917). Serum prealbumin was measured with a nephelometric method (N Antiserum to human prealbumin, Dade Behring, Italy). Serum total protein concentration was measured by the biuret method, and albumin percentage was determined by densitometry, after electrophoretic separation on agarose gel of plasma proteins (Hydragel, Sebia, Benelux). Plasma myoglobin was determined by means of a sandwich immune enzymatic method (Access Myoglobin; Beckman Coulter, Milan, Italy). Serum C-reactive protein level was measured with a nephelometric method (N High sensitivity CRP, Dade Behring, Italy).

Creatinine Generation, Creatinine Metabolism, and Creatinine Index

Creatinine is produced by muscles and is excreted almost exclusively via the kidneys. In steady-state conditions, 24-hour urinary creat-

inine excretion equals creatinine production, thus it is commonly measured to assess the amount of muscle mass.[8,9] Similarly, in anuric MHD patients, creatinine appearance in the blood in the interdialytic period or in the dialysate during the dialytic session may be used to assess creatinine generation. In these patients, creatinine also undergoes an extrarenal degradation. Creatinine generation plus extrarenal degradation of creatinine (or creatinine metabolism) gives the value of creatinine production, which can be used to assess the amount of muscle mass in MHD patients.[10]

Creatinine generation (mg/24 h) was calculated in MHD from the increase in serum creatinine, in the interdialytic period from the end of the midweek dialysis to the beginning of the next dialysis session, assuming a distribution volume of creatinine equal to the volume of TBW, because it has been shown that creatinine distribution space is very close to TBW measured by BIA.[11] Serum creatinine concentration at the end of dialysis was adjusted on the basis of the decrease in TBW caused by ultrafiltration during dialysis.

$$\text{Creatinine generation (mg/24}h\text{)} = \Delta \text{ Serum creatinine} \times \text{TBW} \times 24\text{ h } \Delta \text{ t (h)}$$

Δ t (h): time interval between the end of the midweek dialysis and the beginning of the next dialysis session.

Creatinine metabolism (mg/24 h), or extrarenal degradation rate, was estimated from an extrarenal clearance of 0.038 L/kg BW/ 24 h[12] and the average creatinine concentration in the interdialytic period.[11]

Finally, creatinine index (mg 24/h) was calculated as creatinine generation plus creatinine metabolism.

Dialytic Efficiency

Dialytic efficiency was calculated as single-pool variable volume Kt/V and as a urea reduction ratio with the standard formulas.

Protein Catabolic Rate

Normalized protein catabolic rate (nPCR) was calculated from the interdialytic increase in urea between the end of the midweek session and the beginning of the next dialysis session, and the time interval between the two samples with the standard formula.

Statistical Analysis

The linear correlation and the agreement[13] among the different measurements were tested.

The Student's *t*-test was used to evaluate the statistical significance of the differences between the mean values of different groups of data. A P value lower than .05 was considered statistically significant. Statistical analysis was performed using MedCalc Software, Mariakerke, Belgium, version 6.00.016, 2000.

Results

The results (median, mean, and range values) of sf BIA and mf BIA and of the biochemical parameters commonly measured in MHD patients to assess the adequacy of renal replacement therapy, to evaluate inflammatory and nutritional status, and the protein catabolic rate are reported in Table 1. The values of Kt/V and urea reduction ratios indicate that patients received an adequate dose of dialysis. Serum levels of CRP, often above the upper level of reference range, suggest an inflammatory status in most patients. The wide ranges found for serum creatinine, urea, albumin, prealbumin, and nPCR indicate that this group of patients comprises either malnourished or well-nourished subjects. The wide ranges of creatinine index and of serum myoglobin values suggest wide differences in the amount of muscle mass in the examined patients.

Total Body Water Volumes

A high linear correlation was found between e TBW values and both sf TBW ($r = 0.967$) and mf TBW ($r = 0.971$). However, the agreement plots indicated a statistically significant difference between anthropometrically estimated values of TBW and those measured with either sf BIA (mean difference, +1.72 L, $P < .01$) or mf BIA (mean difference, +1.67 L, $P < .01$). Furthermore, the ranges of agreement (which encompass 95% of patients) between e TBW and either sf TBW or mf TBW were very wide (10.7 and 8.27 L, respectively).

Sf BIA and mf BIA gave very similar results for TBW volumes measured predialysis (Fig 1). In fact, a very high linear correlation was found

Table 1. Clinical Chemistry Determinations, Body Weight, and Body Impedance Analysis Performed with Single-Frequency and Multifrequency Analysis at Midweek Dialytic Session

	Median	Mean	Range
Pre-dialysis			
Serum creatinine, mg/dL	10.9	10.4	4.8–15.8
Serum urea, mg dL	166	157.3	57–242
Serum prealbumin, mg/dL	32.2	30.4	20.2–38
Serum albumin, g/L	39	39.4	34.0–45.0
Serum C-reactive protein, mg/dL	1.1	1.6	0.3–7.3
Serum myoglobin, ng/mL	246	248.4	82–679
Body weight, kg	64.8	68.2	48.9–99.3
sf TBW, L	39.9	37.5	20.8–52.5
mf TBW, L	38.8	37.6	22.8–51.3
sf ECW, L	18.0	17.9	12.2–26.0
mf ECW, L	16.7	16.7	11.5–21.8
sf FFM, kg	50.1	49.1	28.5–71.8
mf FFM, kg	48.3	47.7	24.9–70.9
sf BCM, kg	22.7	23.3	7.7–41.6
mf BCM, kg	30.9	28.9	17.1–42.1
Postdialysis			
Body weight, kg	61.5	64.9	45.9–95.0
sf TBW, L	35.8	33.6	20.7–45.3
mf TBW, L	36.7	34.0	21.4–45.0
sf ECW, L	15.3	14.9	10.1–23.8
mf ECW, L	15.6	15.0	10.8–19.3
sf FFM, kg	45.6	43.9	26.9–61.9
mf FFM, kg	45.4	43.4	22.3–64.5
sf BCM, kg	23.4	22.3	10.0–37.1
mf BCM, kg	29.7	27.1	15.9–38.4
Kt/V	1.47	1.51	1.19–2.20
Urea reduction ratio, %	69.9	70.8	63.9–83.9
n Protein catabolic rate, g/kg	1.06	1.06	0.70–1.44
BW/day			
Creatinine index, mg/24 h	1360	1251	535–2066
Creatinine index, mg/kg BW	20.0	19.0	10.2–29.6

Abbreviations: TBW, total body water; ECW, extracellular water; FFM, fat-free mass; BCM, body cell mass; sf, singlefrequency BIA; mf, multifrequency BIA.

between sf TBW and mf TBW, the slope of their relationship was near 1, and the intercept value was near 0. Thus, mean values of sf TBW and mf TBW were not significantly different (mean difference, 0.04 L). Very high correlation and good concordance were also found between postdialysis measurements, with a mean difference of 0.45 L (Fig 1).

Extracellular Body Water Volumes

Predialysis sf BIA and mf BIA gave quite different results for ECW volumes (Fig 1). In fact, even if a high linear correlation was found between these two measurements, the analysis of agreement plots indicates a relevant and statistically significant difference between sf ECW and mf ECW (mean difference, −1.22 L, $P < .01$). Furthermore, the range of agreement between sf ECW and mf ECW was also very wide (6.9 L). Slightly better results were found after the dialysis. In fact, at this time the values of sf ECW and mf ECW were not statistically different. However, the range of agreement between the two measures was 6.0 L.

Lower values of TBW and ECW were found in female patients. In any case, the relationship between sf BIA and mf BIA seems similar to that of male patients.

Fat-Free Mass

A very high linear correlation was found between sf FFM and mf FFM, measured either predialysis or postdialysis (Fig 2). However, the intercept values were significantly different from 0 (+5.64 kg predialysis, +8.08 kg postdialysis). Mean values of predialysis sf FFM and mf FFM

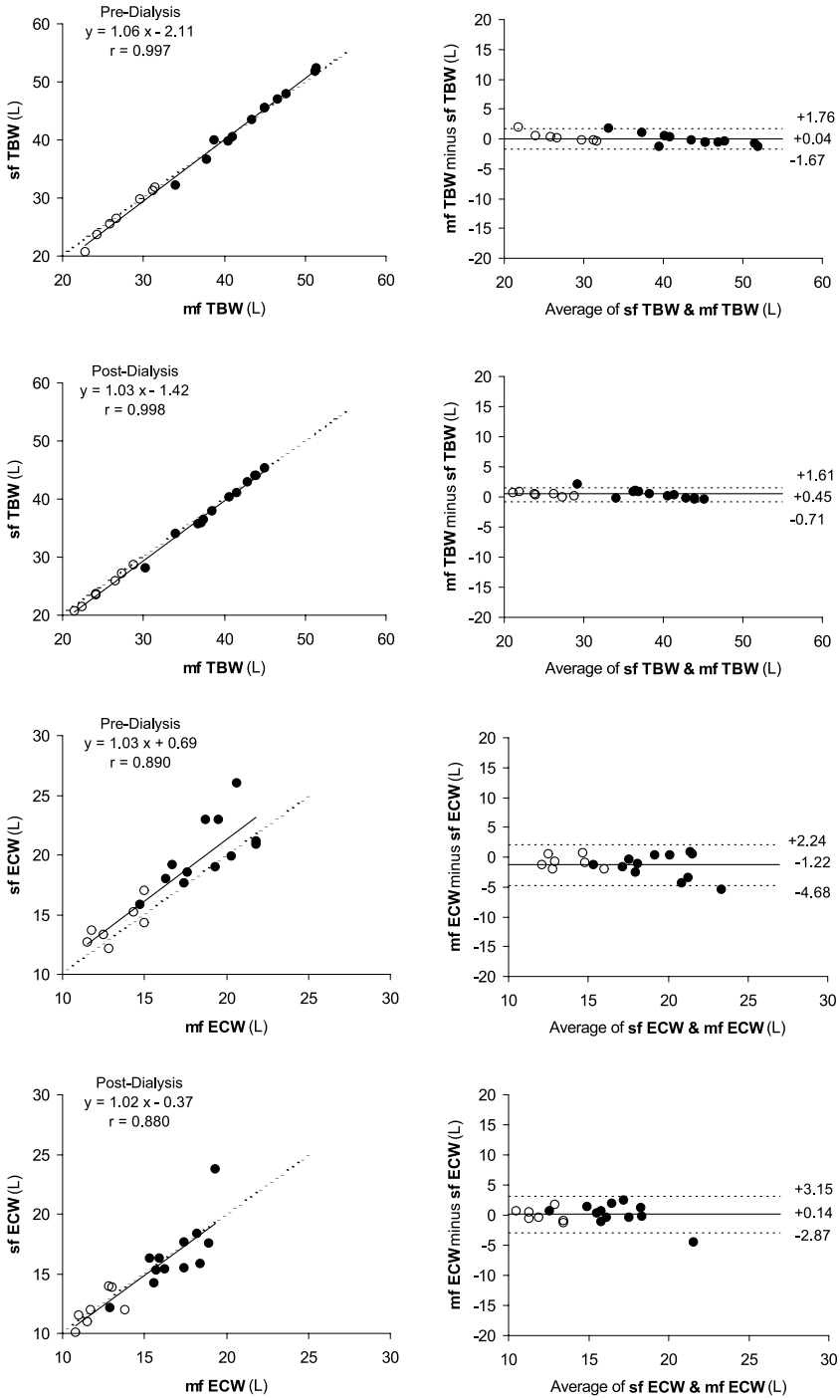

Figure 1. TBW and ECW volumes (L) measured before a midweek dialysis session and 30 minutes after the end of dialysis with BIA. sf TBW and sf ECW are measured with sf BIA; mf TBW and mf ECW are measured with mf BIA (○, female patients; ●, male patients). The equations for linear correlations and the correlation coefficients are reported on the correlation plots (left side). The mean differences and the ranges of agreement (mean difference ± 1.96 SD) are reported on the agreement plots (right side).

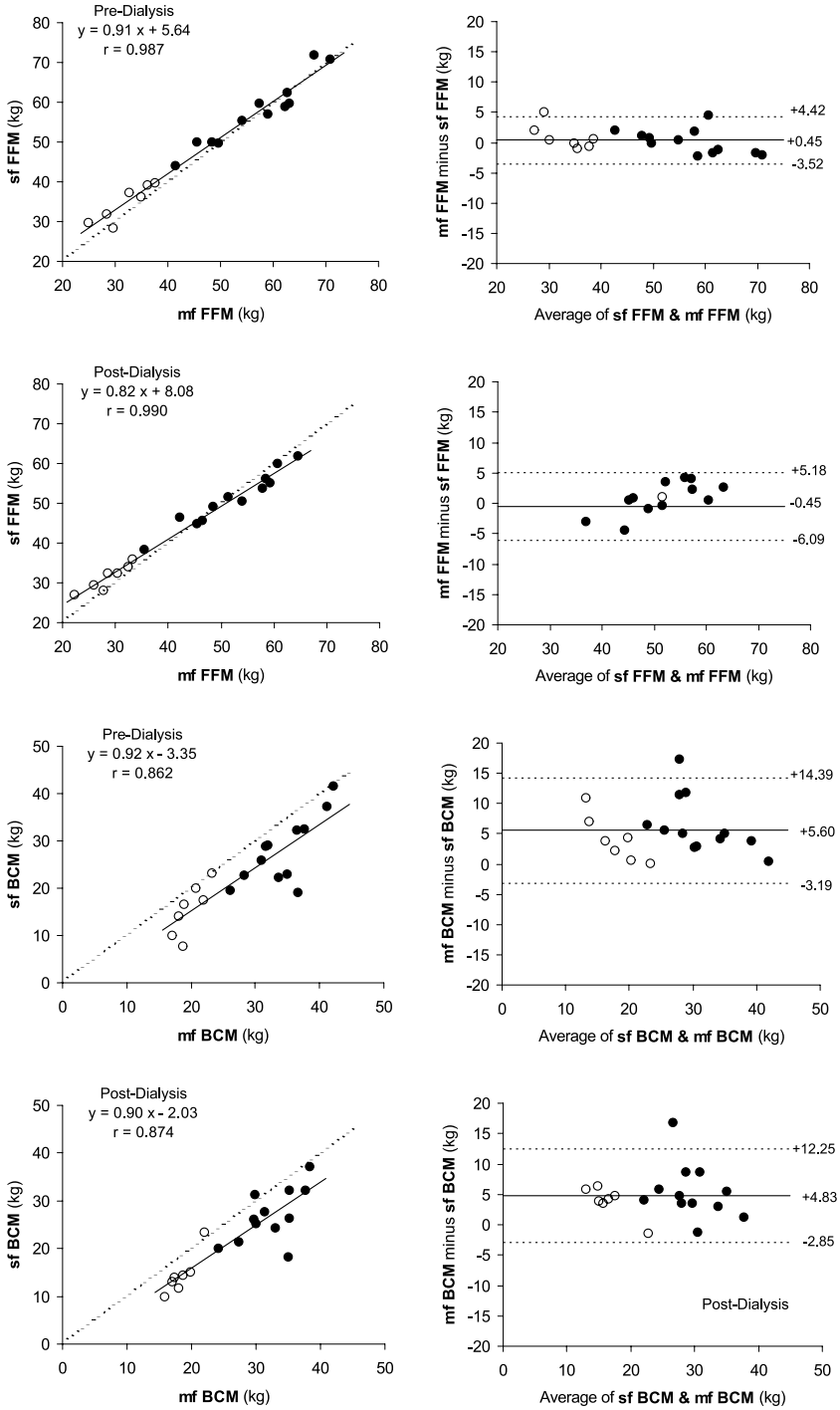

Figure 2. FFM and BCM volumes (kg) measured before and after a midweek dialysis session with BIA. sf FFM and sf BCM are measured with sf BIA; mf FFM and mf BCM are measured with mf BIA (○, female patients; ●, male patients). The equations for linear correlations and the correlation coefficients are reported on the correlation plots (left side). The mean differences and the ranges of agreement (mean difference ± 1.96 SD) are reported on the agreement plots (right side).

were slightly but significantly different (mean difference, mf-sf FFM = 0.45 kg, $P < .05$), and the range of agreement between sf FFM and mf FFM was quite wide (7.94 kg). Mean values of postdialysis sf FFM and mf FFM were not significantly different; however, the range of agreement between sf FFM and mf FFM continued to be quite wide (11.27 kg), and the agreement seems different in female and male subjects.

Body Cell Mass

Predialysis sf BIA and mf BIA gave quite different results for BCM volumes; mf BCM values were higher than sf BCM values. In fact, even if a high and statistically significant linear correlation was found between mf BCM and sf BCM values (Fig 2), the analysis of agreement plots and corresponding data indicate a relevant and statistically significant difference between mf BCM and sf BCM ($P < .001$). Furthermore, the range of agreement of mf BCM with sf BCM and sf1 BCM was also very wide (17.58 and 18.55 kg, respectively). Postdialysis measurement of sf and mf BCM gave no particular improvement with respect to predialysis measures.

A very high linear correlation was found between sf BCM and sf1 BCM (obtained directly from electrical data of sf BIA), either measured predialysis or postdialysis. The slope of their relationship was close to 1, and. the intercept value was not significantly different from 0. However, the mean values of sf BCM and sf1 BCM were slightly but significantly different (−1.82 kg, $P < .001$ predialysis; −1.21 kg, $P < .001$ postdialysis) and the ranges of agreement were 2.81 and 2.32 kg, respectively. The results of BCM show a poor agreement between the measurements obtained with sf and mf BIA.

Attempting to establish the kind of BIA apparatus, the time of BIA measurement, and the parameters of body composition that are more adequate for evaluating the muscle mass and the nutritional status of MHD patients and the results of FFM and BCM obtained with sf and mf BIA, predialysis and postdialysis, were compared with the values of creatinine index and with serum levels of myoglobin, prealbumin, and albumin. All of the different measurements of FFM and BCM had statistically significant linear correlations with the values of creatinine index (Fig 3), which is a marker of the amount of muscle mass that a patient has. In particular, the results of FFM and BCM obtained with mf BIA, both predialysis and postdialysis, had higher values of the correlation coefficient r with the creatinine index than the results of sf BIA. Furthermore, the values of mf BCM, either predialysis or postdialysis, had a significant correlation (predialysis, $r = 0.696$, $P < .001$; postdialysis, $r = 0.688$, $P < .005$), slightly higher than that of sf BCM ($r = 0.689$, $P < .005$; $r = 0.617$, $P < .005$) with the serum levels of myoglobin, a low-molecular-weight protein that is produced by muscle cells. The values of mf FFM, either predialysis or postdialysis, also had a significant correlation (predialysis, $r = 0.666$, $P < .005$; postdialysis, $r = 0.663$, $P < .005$), similar to that of sf BCM ($r = 0.651$, $P < .005$; $r = 0.656$, $P < .005$) with the serum levels of myoglobin. These data indicate that mf BCM is the measurement of body composition best correlated with the amount of muscle mass, and the significance of the correlation is similar for predialysis and postdialysis measurements.

Statistically significant correlations were found between serum levels of prealbumin and either predialysis or postdialysis values of sf FFM (predialysis, $r = 0.5784$, $P < .01$; postdialysis, $r = 0.5806$, $P < .01$), mf FFM ($r = 0.5927$, $P < .01$; $r = 0.5665$, $P < .05$) and mf BCM ($r = 0.560$, $P < .05$; $r = 0.5566$, $P < .05$). A significant correlation with serum levels of prealbumin was found for postdialysis values of sf BCM ($r = 0.5265$, $P < .05$, but not predialysis sf BCM. Only sf BCM values, both predialysis and postdialysis, were significantly correlated ($r = 0.514$, $P < .05$; $r = 0.5477$, $P < .05$) with serum concentrations of albumin.

Discussion

Body mass index (BMI), which relates body weight to squared height, is the most commonly used parameter to evaluate nutritional status. BMI can give useful information in population studies, whereas it is less useful in the evaluation of individual subjects. In fact, in overweight patients BMI cannot discriminate among increase of fat, muscle mass, or body water volumes. On the other hand, in malnourished patients BMI underestimates the severity of malnutrition, because in protein-energy malnutrition the decrease of fat and muscle mass is accompanied by an increase in ECW volume. Therefore, an accurate evaluation

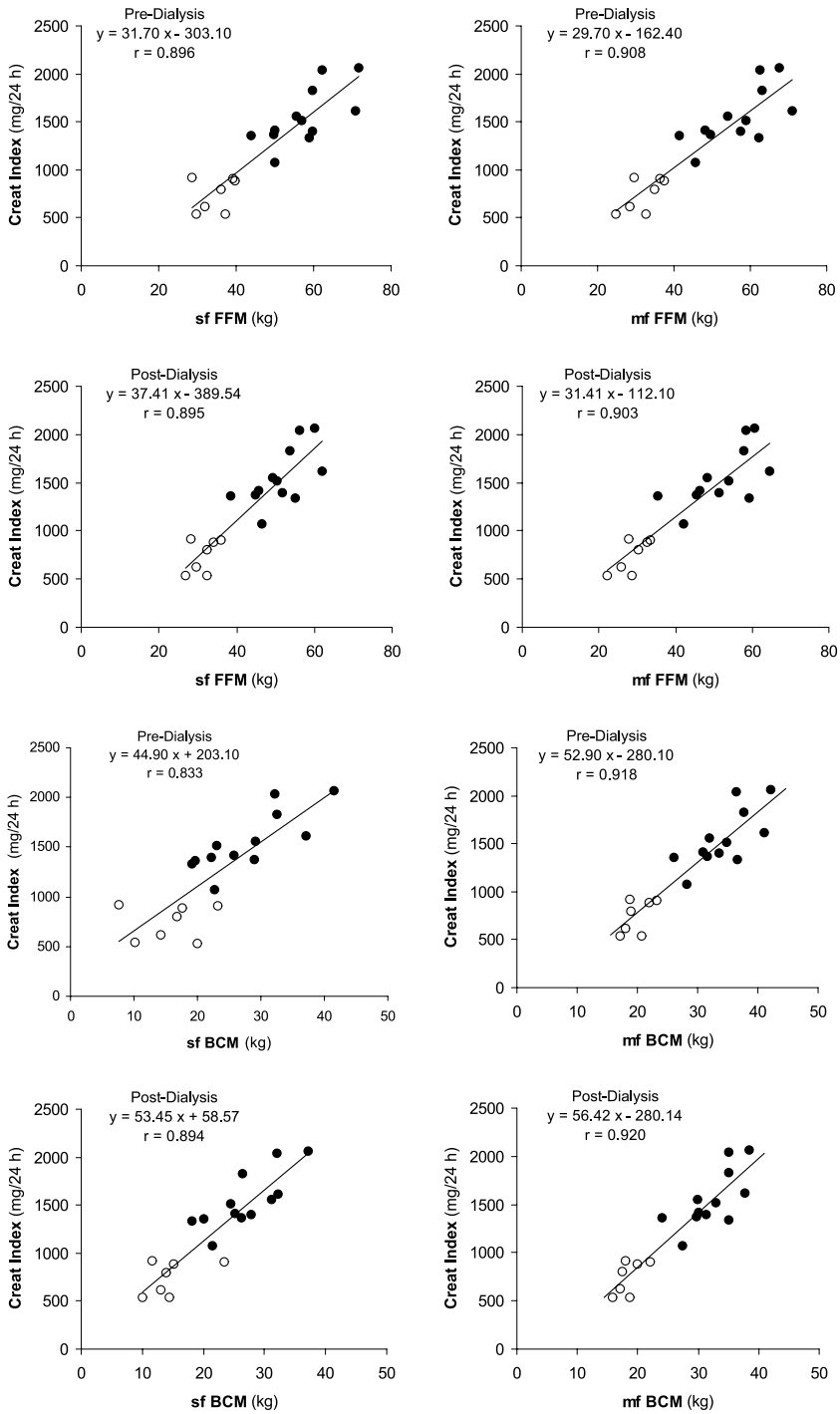

Figure 3. Creatinine index (mg/24 h) versus FFM and BCM volumes (kg), measured before and after a midweek dialysis session with BIA. sf FFM and sf BCM are measured with sf BIA; mf FFM and mf BCM are measured with mf BIA (○, female patients; ●, male patients). The equations for linear correlations and the correlation coefficients are reported on the correlation plots.

of nutritional status needs a precise quantitative assessment of the constituents of body mass and the evaluation of the distribution of body fluids. DEXA is a recommended method for body composition analysis in adult dialysis patients.[1–2] In fact, DEXA allows measurement of fat mass, lean body mass, and bone mass. However, DEXA cannot give an exhaustive evaluation of nutritional status because it does not measure body fluids compartments and body cell mass, which is the edema-free lean body mass. Thus, DEXA measurements are commonly used to assess body fat. It is worthy of notice that not all malnourished patients present a decrease in body fat content.

BIA is a simple and nonexpensive technique that should allow a thorough evaluation of the nutritional status because it estimates the most relevant components of body mass and the body fluids compartments. However, data from published papers aimed at assessing the adequacy of sf and mf BIA for the evaluation of body fluids compartments (TBW and ECW) and of body composition (FFM and BCM) seem quite conflicting. In fact, results in healthy subjects indicate that TBW can be adequately estimated by means of sf BIA, and ECW by means of dual-frequency BIA.[14] Furthermore, bioimpedance spectroscopy seems to improve the prediction of ECW.[15] In renal transplantation patients mf BIA, compared with isotope dilution techniques, resulted in suitable measurement of TBW, whereas the agreement between the isotope dilution method and mf BIA for the measurement of ECW was not satisfactory.[16] In renal transplantation patients, sf BIA was found adequate for highlighting changes in body compartments not only in patients with graft dysfunction, but even in those with good graft function.[17,18] In hemodialysis patients, a good correlation and excellent agreement were found between TBW measured by sf BIA and D_2O dilution.[5] Mf BIA seemed very useful in assessing both TBW and body composition in end-stage renal disease patients.[6] In patients on long-term dialysis therapy, using DEXA as a reference method, the method of skinfold thickness was preferable over BIA, which showed gender-specific variability in the assessment of body fat.[19] Other articles report that in hemodialysis patients the agreement between mf BIA and tracer dilution techniques in the assessment of TBW and ECW is unsatisfactory; in any case, mf BIA adequately predicted acute changes in ECW.[20]

In addition to the conventional whole-body sf BIA, a new approach for routine monitoring of the body fluid variation in the single patients, based on the analysis of the bivariate distribution of the impedance vector, has been proposed[21] and applied in hemodialysis patients.[22] This method avoids potential difficulties caused by the use of prediction equations, which are necessary for classic BIA analysis. However, in a large population study performed on normal subjects and on dialysis patients, the results obtained by means of phase angle analysis, bivariate analysis, and prediction equation method, using sf BIA, corroborate each other.[23] On the other hand, the phase angle and bivariate analysis do not give numerical values for the different body compartments (FFM, BCM, TBW, ECW, etc), thus the interpretation of results and of the variations in the time is less intuitive than with conventional BIA. Furthermore, the measurement of phase angle and the bivariate analysis need the measurement of both resistance and reactance vectors of impedance, which are measurable with the sf BIA apparatus but not with the mf BIA apparatus that we used. For all of these reasons, we decided to analyze all of our BIA measurements with the classic method of prediction equations.

The ideal time to perform the analysis of body composition by means of BIA has not been clearly established. It has been reported that the BIA can be appropriately performed in the postdialysis period of 2 hours in patients treated only with a standard diffusive technique.[24]

Our data indicate a similar relationship between sf and mf TBW, both predialysis and postdialysis. In fact, the present study was performed in a small group of nonhomogeneous MHD patients, differing in age, dialysis vintage and technique, nutritional status, and possibly in achievement of "ideal" body weight. In spite of all of these difference, sf BIA and mf BIA clearly gave very similar values for TBW, measured predialysis and postdialysis at a midweek hemodialysis session. To the contrary, in our patients, predialysis TBW, estimated from anthropometric data, gave significantly different results from both sf TBW and mf TBW. For practical reasons, we did not measure, as a gold standard, the TBW by

the D_2O dilution method. However, it seems reasonable to assume that sf and mf TBW values that were very similar to each other, being measured by means of sf BIA and mf BIA, which rely on very different physical principles, are probably more accurate than TBW volumes estimated from anthropometric data. These results confirm that BIA provides more consistent and reproducible results than standard anthropometry alone.[25] Furthermore, our results agree with the reported significant overestimation of modeled urea volume in MHD patients by anthropometrically estimated TBW.[26] In any case, BIA is considered the most accurate surrogate marker for the measurement of TBW in end-stage renal failure patients.[6] To the contrary, BIA seems not fully adequate for measuring ECW. In fact, sf and mf BIA gave significantly different results for ECW volumes, particularly when measured predialysis. Further studies should address the assessment of ECW volumes in hemodialysis patients.

Body cell mass, or edema-free lean body mass, is the constituent of body mass with the highest metabolic activity. Muscle mass represents the major constituent of BCM. Thus, the measurement of BCM can give important information on nutritional status of MHD patients, who are at high risk of protein-energy malnutrition with reduction of muscle mass and increase in ECW volumes. Because the value of BCM is independent from the amount of ECW, it should be more adequate than the measurement of FFM, which is influenced by ECW, to assess malnutrition in MHD patients.

In normal healthy subjects and in patients with the human immunodeficiency virus, body composition (TBW, FFM, and BCM) was accurately estimated with sf BIA, and such estimates are considered sufficiently precise for use in clinical investigation and practice.[27] Similarly, using an mf BIA–derived equation, it was possible to accurately estimate FFM and total body nitrogen, which is a reference marker of nutritional status.[6] Furthermore, the measurements of BCM, obtained with sf BIA, were in excellent agreement with those obtained with deuterium oxide and sodium bromide isotope dilution methods, indicating that BIA is a valid and reliable method of nutritional assessment in MHD patients.[5] Published data seem to indicate that both sf BIA and mf BIA can be used for the analysis of body composition. However, there are no exhaustive studies addressed to compare these two techniques.

In the present study, body composition analysis with sf BIA was compared with mf BIA. The results of FFM and mainly those of BCM showed a poor agreement between the measurements obtained with sf and mf BIA. However, all of these measurements significantly correlated with different biochemical indicators of nutritional status. FFM and BCM values, particularly those obtained with mf BIA, were more strictly correlated with biochemical markers of muscle mass, such as creatinine index and myoglobin, than with indicators of visceral proteins, such as albumin and prealbumin. These results, which probably depend on the fact that muscle mass is an important constituent of FFM and the major constituent of BCM, are in agreement with the extensive study by Chertow et al in hemodialysis patients.[28] These investigators found that BCM correlated more closely with serum creatinine than with albumin and prealbumin concentrations, suggesting that bioimpedance and biochemical markers capture somewhat different dimensions of nutritional status. Our previous data showed that in chronic kidney disease patients with different degrees of renal function, it is possible to estimate the daily creatinine production and excretion from the values of FFM and BCM obtained with sf-BIA.[29–30]

Preliminary data in healthy volunteers, using as a reference method the measurement of total body potassium, suggest that it should be possible to measure accurately BCM with sf or mf BIA, with device-specific equations.[31]

The measurement of BCM obtained directly with sf plethysmograph soft tissue analyzer (STA)-BIA, without the need for measurement of height and weight, could greatly simplify the analysis of body composition in particular groups of patients, such as those in intensive care units. Our results indicate that this estimate of BCM was strictly correlated with but not identical to the standard BCM obtained by combining body weight and height to electrical data of sf BIA. The few other data available indicate that this estimate of BCM is correlated with BCM measured from total body potassium, although differing significantly from the identity, whereas the BCM values obtained with standard sf BIA were more similar to BCM measured by total body potassium; thus

this simplified method cannot be used with confidence.[32]

As far as body composition analysis is concerned, the results of this study suggest that mf BIA is more adequate than sf BIA for the evaluation of muscle mass in MHD patients because the highest correlations were found between data derived from mf BIA, namely BCM, and the creatinine index, which is a well-documented parameter of muscle mass, and serum myoglobin levels, which can be proposed as a simple tool for estimating muscle mass in MHD patients.

Conclusions

TBW volume can be estimated with enough confidence from both sf and mf BIA in maintenance hemodialysis patients. On the contrary, one should be very prudent in evaluating the results of body water compartments analysis because the measurement of ECW volume may be significantly different depending on the method used. Both sf and mf BIA estimate parameters of body composition, FFM, and BCM, which are significantly correlated with different indicators of muscle mass and nutritional status. However, mf BIA seems more adequate than sf BIA for estimating muscle mass in dialysis patients.

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