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Body fluid volume and nutritional status in hemodialysis: vector bioelectric impedance analysis

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Key words
impedance – vector-BIA – body composition – hemodialysis – nutritional status – volume – Bilbrey score

Abstract. Background: Protein-energy malnutrition and hypervolemia are major causes of morbidity and mortality in patients on chronic hemodialysis (CHD). The methods used to evaluate nutritional status and volume status remain controversial. Vector bioelectric impedance analysis (vector- BIA) has recently been developed to assess both nutritional status and tissue hydration. The purpose of the study was to assess the nutritional status and volume status of patients on CHD with conventional nutritional assessment methods and with vector-BIA and then to compare the resulting findings. Methods: 76 Mexican patients on CHD were studied. Nutritional status and body composition were assessed with anthropometry, biochemical variables, and the modified Bilbrey nutritional index (mBNI), the results were compared with both conventional BIA and vector-BIA. Results: The BNI was used to determine the number of patients with normal nutritional status (n = 27, 35.5%), and mild (n = 31, 40.8%), moderate (n = 10, 13.2%) and severe malnutrition (n = 8, 10.5%). Patients displayed shorter vectors with smaller phase angles or with an overhydration vectorial pattern before the initiation of their hemodialysis session. There was general improvement to normal hydration status post-dialysis ($p < 0.05$); however, 28% remained overhydrated as assessed by vector-BIA. The vector-BIA results showed that worse malnutrition status was associated with greater volume overload ($p < 0.05$). Diabetes mellitus (DM) was associated with shorter vectors with smaller phase angles (a vectorial pattern of overhydration and cachexia) ($p < 0.05$). Patients with lower serum creatinine presented with shorter vectors and smaller phase angles (vectorial patterns of malnutrition and/or overhydration) ($p < 0.05$). In women, lower serum albumin (< 3.4 g/dl) correlated with greater overhydration and malnutrition ($p < 0.05$). Conclusions: In this population, the vector-BIA showed that 28% of the population remained overhydrated after their hemodialysis session. Diabetics and those with moderate or severe malnutrition were more overhydrated, which is a condition that may be associated with increased cardiovascular morbidity. Because nutritional and volume status are important factors associated with morbidity and mortality in CHD patients, we focused on optimizing the use of existing methods. Our studies suggest that vector-BIA offers a comprehensive and reliable reproducible means of assessing both volume and masses at the bedside and can complement the traditional methods.

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Introduction

Several studies have shown a high incidence and prevalence of protein-calorie malnutrition in hemodialysis (HD) and peritoneal dialysis (PD) patients [1, 5, 20]. Some causes that contribute to malnutrition are: insufficient food intake, deficient dialysis, delayed gastric emptying, dietary restrictions, depression, anorexia, metabolic and endocrine alterations (such as resistance to insulin, catabolic effects of the parathyroid hormone, resistance to insulin-like growth factor 1, metabolic acidosis and alterations of amino acid metabolism), and the effects of dialysis itself (amino acid loss in dialysis solution and the catabolic effects of the dialyzing membrane). The adverse consequences of a poor nutritional state are multiple and diverse, and include poor wound healing and susceptibility to infections, leading to increased morbidity, frequent hospitalizations and an increase in mortality when compared to the general population.

Cardiovascular disease is the greatest cause of morbidity and mortality in dialysis. Traditional risk factors such as smoking and advanced age, as well as non-traditional factors, all cause elevated rates of cardiovascular disease. Hypervolemia is associated with left ventricular hypertrophy, arterial hypertension, and endothelial damage. The maintenance of "dry weight" in HD is associated with several factors, including residual renal function, ultra filtration, and salt intake, which influences volume restriction. Several methods have been employed to assess volume status. Traditional methods, most commonly those derived from mathematical formulae, are usually employed [12].

Evaluations of the nutritional status of the HD patient have been accomplished with various clinical, anthropometric, and biochemical indicators, as well as by their combinations, in order to establish grades.[6] Some of the tools described include monitoring nutritional intake (reminder, interview, consumption frequency), anthropometry, body compo analysis including BIA, dual electron X-ray absorptiometry (DEXA) scans, and scoring systems for nutritional diagnosis (subjective global evaluation, compounded indixes) [6]. A combination of indicators is required to obtain a reliable diagnosis.

Recently, Piccoli et al. [17] proposed and validated [16, 18, 19] a method to evaluate the state of hydration and nutrition both in normal individuals and in those with diverse volume states in disease. The vector-BIA method bypasses all of the assumptions made in the traditional BIA approach, which use regression equations. The vector-BIA method makes no assumptions about hydration proportion tissue, length of conductor, etc, and instead directly measures the resistance (R, (Ω)) (the opposition to the flow of current through a body) and the reactance (Xc, (Ω)) (the phase-shift of the current as it passes through biological membranes and tissue interfaces). Each variable (R and Xc) is standardized by the individual's measured height (H) in meters (R/H, Xc/H, Ohms/M). The vector-BIA method shows the correlation between the R/H and Xc/H on an X-Y graph or an RXc point graph. Plotting the (R, Xc) on the RXc graph, with each variable standardized by the patient's height, produces a point with which to form a vector from the origin. The vector has a length, an angle, and a direction. The vector or point is then compared to a large population of healthy individuals and expressed as within either 50%, 75%, or 95% confidence intervals of the healthy population or tolerance ellipses. The method has been further developed into a Z-score graph that takes into account the patient's gender, race, and body mass index as well as the impedance plethysmograph. Thus, different individuals can be compared to each other and to a healthy population of similar demographics regardless of the type of plethysmograph used. This bypasses the need for an ethnicity-specific, gender-specific graph. These two methods, the RXc graph and the RXc Z-score, can directly and simultaneously provide a qualitative estimation of variations in a patient's tissue hydration status as well as changes in nutritional status. [16, 17, 19] A normal individual's impedance vector is expected to fall within the reference 75% tolerance ellipse [TE] [16]. Vectors to the outside of the lower pole of the TE are consistent with clinically apparent edema. Vectors beyond the 75% TE in the upper pole are consistent with dehydration that is clinically apparent.

Repeated measurements in the same individual over time can evaluate the direction of vector displacement (vector migration). Migration can occur over the long axis of the TE as represented by the vector's length. The vector length represents the volume component such that a shortening of the vector parallel to the long axis of the TE will occur with increased hydration while a vector lengthening will occur with decreased hydration. On the other hand, over the same resistance, the nutritional status of the patient can be evaluated by a phase angle (PA). The PA is the arctangent of Xc/R, and it can be interpreted as more or less cell mass (i.e., the better the nutrition, the healthier the biological membranes and cytoplasm) [18]. By assessing the impedance as the PA and vector length (Figure 1a), it is possible to evaluate the patient's nutrition and hydration simultaneously. At the extremes of body composition, one can clearly discern changes toward obesity (short vector, wide PA), muscularity (long vector, wide PA), leanness (longer vector, smaller PA) and cachexia (shorter vectors, with extremely small PA) [18, 19]. The great advantage of this method over other methods of body composition

analysis is that it allows information about changes in both tissue hydration and soft tissue mass to be obtained simultaneously, independent of regression equations with inherent assumptions and body weight, which is itself dependent on volume status. Furthermore, the hydration state and body composition of subjects with complex hydration and nutritional states may be evaluated and followed over time. More precise data have been obtained by analysis of impedance vectors than by other methods of body composition analysis.

In this study, we hypothesized that vector-BIA is a good tool for assessing nutritional and volemic status in HD patients. We assessed the body composition of CHD patients according to the Bilbrey Index and other conventional methods of evaluating the nutritional status, and compared these traditional methods to the vector-BIA approach.

Materials and methods

76 patients on thrice-weekly, alternate-day sessions of CHD in a Mexico City hospital HD unit were studied. All patients underwent a nutritional status and body composition evaluation at least twice, 48 h apart, using the following methods:

a) Anthropometry: The following measures were made: weight, height, skin folds: bicipital, tricipital, subscapular, and suprailiac, arm circumference and elbow breadth. With these measures, the following data were obtained: percent of ideal body weight (IBW), arm muscular area, and percentage of body fat. Each patient was weighed before and after the HD session. Anthropometric measures were obtained post-dialysis.
b) Laboratory: The following biochemical variables were obtained: serum albumin (SAlb), creatinine (Scr), blood urea nitrogen (BUN) and total lymphocyte count. Kt/Vurea was calculated in all patients using a single-pool method.
c) Subjective global assessment (SGA): The SGA was used to assess the presence of signs and symptoms of malnutrition.
d) The Bilbrey nutritional index (BNI) [3]: The BNI was employed to establish a nutritional diagnosis of each patient. The Bilbrey method includes seven clinical, biochemical, and anthropometric parameters: weight/height ratio, triceps skinfold, midarm muscle circumference, midarm muscle area, serum albumin, serum transferrin, total lymphocyte count, and the subjective global assessment. The results of the anthropometric measurements were classified into four categories of nutritional status. Patients were designated as: normal (if within 10% of the ideal standard), mild deficit (if 80% – 90% of ideal), moderate deficit (if 60% – 80% of ideal), and severe deficit (if less than 60% of ideal). Biochemical parameters and physical examinations were similarly scored, with each given a score of 3 (if normal), 4 (if mildly decreased), 5 (if moderately decreased), or 6 (if severely decreased). Originally, the categories were defined by total scores, as follows: normal = 25, mild 26 – 28, moderate 29 – 31, and severe malnutrition > 32. However, the final score of the BNI was modified to exclude transferrin, as this determination was infrequent in routine biochemical exams.

Patients underwent BIA 20 – 30 min before and after HD using the Bodystat Quad Scan 4000 Body Composition and Fluid Monitoring System. Total body water (TBW), body fat and lean body mass were determined from the BIA. Vector-BIA was used to determine the state of nutrition and hydration. Patients whose vectors fell in the right half of the reference ellipses for the Mexican population [7] were considered malnourished. Descriptive statistics were used to obtain measures of central tendency (means ± SD) of the studied variables. Correlation between the conventional nutritional status indicators and the vector-BIA was assessed using Pearson correlation, and the Hotteling T^2-test was used to compare vectors under different clinical conditions. We used the correction Dunnet's C-test for comparing the vector-BIA properties with the traditional nutritional measurement methods, as there were no equal variances with the conventional analysis of variance (ANOVA). A p value < 0.05 was considered significant. Statistical analysis was performed with the GraphPad InStat V.3.01 software.

Table 1. Anthropometric characteristics by gender.

	Women	Men	p value
Weight pre-HD (kg)	58.8 ± 11.2	68.7 ± 9.3	< 0.0001
Weight post-HD (kg)	57.0 ± 11.0	66.9 ± 8.9	< 0.0001
Ultrafiltrate (l)	1.7 ± 0.9	1.7 ± 1.0	NS
Height (cm)	152.3 ± 6.2	164.5 ± 6.3	< 0.0001
BMI (kg/m^2)	24.5 ± 4.2	24.7 ± 2.9	NS
% Weight/Height	112.0 ± 18.3	110.4 ± 13.7	NS
% Tricipital skinfold	118.8 ± 38.8	249.1 ± 88.6	< 0.0001
% Arm circumference	104.3 ± 16.2	97.3 ± 11.8	0.0416
% Muscular arm area	128.4 ± 45.7	89.7 ± 30.3	< 0.0001
% FAT	35.5 ± 6.5	26.6 ± 4.8	< 0.0001

Table 2. Body composition using BIA by gender.

Measure	Women			Men		
	Pre- HD	Post- HD	p	Pre- HD	Post- HD	p
Fat %	34.3 ± 8.5	36.6 ± 8.5	NS	20.0 ± 6.3	22.2 ± 6.3	NS
Fat kg	20.6 ± 7.6	21.3 ± 7.5	NS	13.9 ± 4.9	15.1 ± 5.0	NS
Lean mass kg	38.1 ± 6.3	35.7 ± 6.0	NS	54.8 ± 7.3	51.8 ± 6.5	NS
TBW %	53.6 ± 7.9	51.8 ± 8.3	NS	61.5 ± 6.6	59.3 ± 6.8	NS
TBW L	30.8 ± 3.8	28.9 ± 3.5	0.0178	42 ± 5.0	39.3 ± 4.4	0.0324
Imp. 50 kHz	559 ± 83.3	626.4 ± 99.9	0.0010	464.8 ± 79.7	515.4 ± 84.7	0.0191
Phase Angle(°)	4.3 ± 1.2	4.9 ± 1.3	NS	5.3 ± 1.55	6.3 ± 2.8	NS
R (Ω)	555.3 ± 84.0	622.8 ± 99.9	0.0011	461.0 ± 79.7	510.7 ± 84.3	0.0194
Xc (Ω)	43 ± 14.3	54.4 ± 19.1	0.0024	43.9 ± 15.9	57.9 ± 31.1	0.0250
R/H (Ω/m)	365.41 ± 59.6	410.1 ± 71.2	0.0022	279.9 ± 48.9	309.7 ± 51.1	0.0185
Xc/H (Ω/m)	28.4 ± 9.7	35.8 ± 12.9	0.0034	26.5 ± 9.8	32.6 ± 11.4	0.0248

TBW = total body water, R = resistance at 50 kHz, Xc = reactance at 50 kHz, R/H = resistance/height, Xc/H = reactance/height.

Results

76 Mexican, CHD patients were studied (43 women and 33 men). The mean age was 46.8 ± 16.3 years, time on dialysis 30.5 ± 17.1 months, mean Scr 8.9 ± 3.4 mg/dl, mean BUN 57.1 ± 21.9 mg/dl, mean Salb 3.9 ± 0.4 g/l, mean total lymphocyte count 1,430 ± 577 cel/mm^3, and the mean Kt/Vurea was 1.44 ± 0.33 (1.30 ± 0.23 for men and 1.45 ± 0.37 for women). 22 of the studied patients (29%) were diabetics.

Table 1 shows anthropometric indicators, of which only BMI and percent weight/hight were similar in men and women. The average ultrafiltrate volume per HD session was 1.7l for both men and women. Data on body composition obtained by BIA pre- and post-HD are shown in Table 2. Differences in pre- and post-HD values of TBW in L, R, Xc, and height-corrected R and Xc, showed statistically significant differences both in men and in women. Table 3 shows the differences in body composition by BIA pre- and post-HD. According to the modified BNI (mBNI), 36% of the studied population was within normal parameters, 40% had mild malnutrition and 24% showed moderate or severe malnutrition.

The pre- and post-HD vector-BIAs are shown in Figure 1b , and reveal that the pre-HD vectorial patterns of a large number of patients had the shortest vectors parallel to the major axis (i.e., showed volume overload). This persisted after dialysis treatment, even in

Table 3. Body composition differences between pre and post HD session.

	PRE- HD	POST- HD	Δ
Fat %	28.0 ± 10.4	30.2 ± 10.5	2.2
Fat (kg)	17.7 ± 7.4	18.5 ± 7.2	0.8
Lean Mass (kg)	45.5 ± 10.8	42.9 ± 10.3	–2.6
TBW (%)	57.0 ± 8.4	55.1 ± 8.6	–1.9
TBW (l)	35.7 ± 7.1	35.5 ± 6.6	–0.2

TBW = total body water.

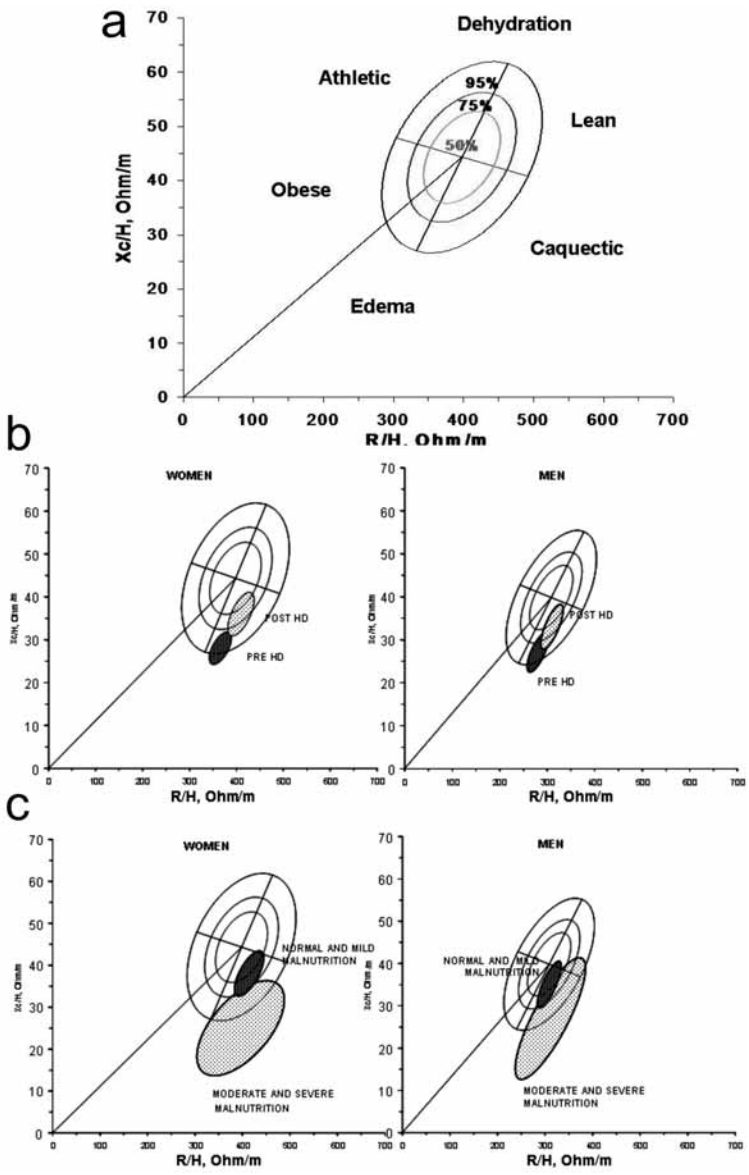

Figure 1. a: RXc graph view and interpretation. b: Vector BIA pre and post HD by gender. c: Nutritional status and vector- BIA by gender.

the absence of clinical edema. The difference between vectors pre- and post-HD, both in men and in women, was statistically significant ($p < 0.05$).

Impedance vectors were assessed in relation to nutritional status, and the population was divided into two large subgroups according to the modified mBNI: Normal status to mild malnutrition (women: n = 34; men: n = 24) and moderate to severe malnutrition (women: n = 9; men: n = 9) (Figure 1c). Vectors from the more severely malnourished group showed greater overhydration ($p < 0.05$ both for men and women). The gender-specific confidence ellipses were especially large and overlapping (Figure 1c) due to the small sample size (n = 9), even though it can clearly be seen that both groups have different volemic statuses.

When the vector-BIA pattern was compared between patients with different SCr levels before HD (Figure 2a), the results showed that patients with levels below the mean (SCr < 7.63 mg/dl for women (n = 24) and < 10.94 mg/dl for men (n = 22)) had vectorial patterns of overhydration and of severe malnutrition (cachexia) ($p < 0.05$ both for men and women).

Figure 2b shows that the impedance vectors of patients with SAlb < 3.5 g/dl (women: n = 10; men: n = 8) displayed overhydration as well as a cachexia vectorial pattern, although this was statistically significant only in women ($p < 0.05$).

Different vector-BIA length could differentiate between patients with and without diabetes mellitus similar to previous findings [19], in which diabetics tended to have shorter vectors in comparison to non-diabetics. In this study, our diabetic patients showed a clear trend towards overhydration as well as cachexia (Figure 2c) in men as well as in women ($p < 0.05$).

In Table 4, we show a comparison between the two nutritional measurements (mBNI and vector-BIA). Patterns with a decrease in both R/H and Xc/H indicate fluid overload. Patterns with an increase in R/H and a decrease in Xc/H indicate loss of soft tissue mass, as in malnutrition or inflammation. As patient nutritional status deteriorated, the vector-BIA components (R, Xc, R/H, Xc/H and PA) diminished, indicating migration towards the patterns of cachexia and edema.

Finally, dialysis adequacy as measured by Kt/Vurea (mean value 1.44) was compared using vector-BIA, dividing the study popula-

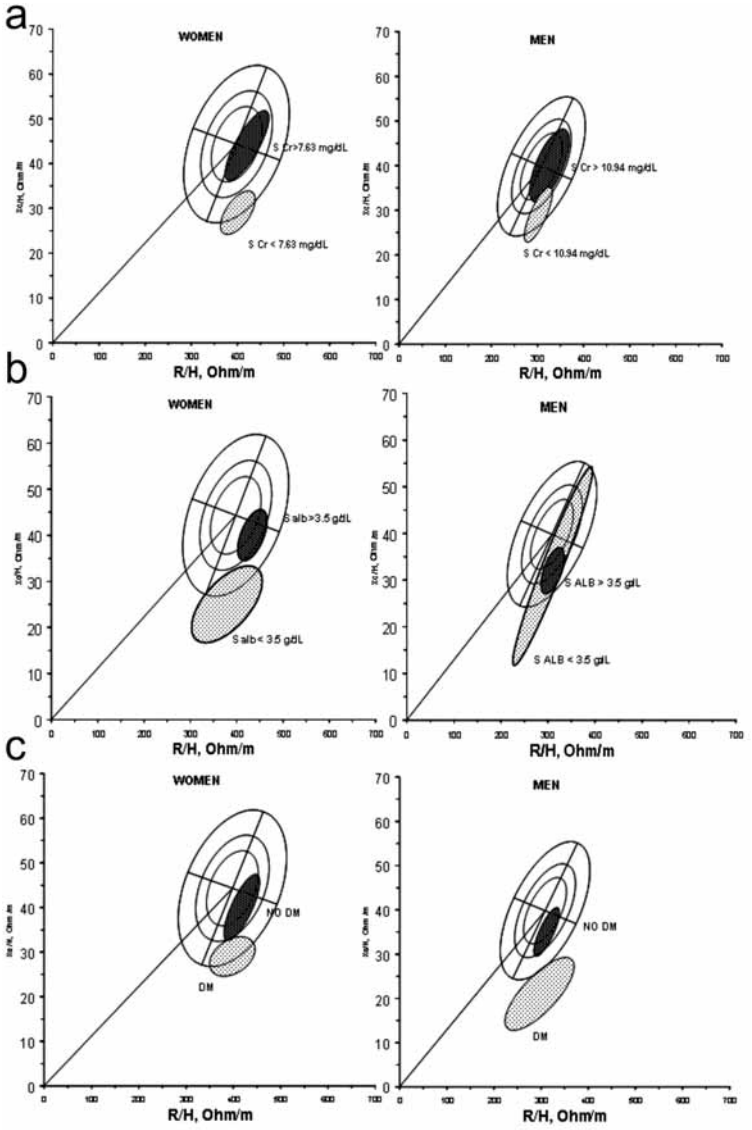

Figure 2. a: Vector-BIA and serum creatinine by gender. b: Vector-BIA and serum albumin by gender. c: Vector-BIA and diabetes mellitus by gender.

tion into those over and under Kt/V = 1.2, according to international standards. Dialysis adequacy as determined by Kt/Vurea did not show any correlation with vectorial patterns of hydration and/or nutrition (data not shown).

Discussion

Protein-calorie malnutrition affects a high percentage of the CHD population and constitutes a high risk factor of morbidity and mortality [14]. Several assessment methods for nutritional status have been employed on CHD patients, including diet surveys, anthropometry and biochemical indicators [1, 14]. Most of these procedures are either costly or difficult to apply in the clinical setting [14]. An accurate diagnosis of body composition and volume status in CHD patients is clearly important in order to adequately prescribe ultra filtration as well as to better determine nutritional status. At present, nutritional diagnosis is quite imprecise and is based mainly on biochemical and anthropometric indicators alone.

The present study used vector-BIA and a composite nutritional index (the modified Bilbrey nutritional index) to assess the nutritional as well as the hydration status of CHD patients. It is well known that a biochemical evaluation is complementary to the information obtained by other nutritional evaluation processes, e.g., clinical, diet, and anthropometry. The biochemical indicators used herein were SAlb, Scr, total lymphocyte count and BUN. Of the mentioned indicators, SAlb is probably the most widely used in a diversity of chronically ill patients. However, it should be considered that in patients on dialysis, SAlb is influenced by other co-existing problems besides malnutrition, chiefly by the presence of a systemic inflammatory state. In the present study, the SAlb levels fell to a mean within the reference values for normality, 3.9 g/dl, an uncommon situation in CHD patients in our environment. While other authors [18] have found that there is no stable, definite correlation between either vector component and SAlb, we found this association in women, but not in men, with SAlb < 3.5 g/dl, probably because of the small sample size of males. Similarly, the mean lymphocyte count was very close to normal. Low SCr versus high SCr in patients on CHD has been reported more frequently in hospitalized patients [15]. This was not seen in our study, where the mean Scr was 8.9 ± 3.4 mg/dl.

Anthropometric evaluation has been traditionally considered unreliable in CHD patients, as tissue hydration is altered [15]. Because anthropometric measurements are time-consuming and depend on trained staff, most clinical practice groups do not employ them. The present study included the following anthropometric measurements: percent weight/height, arm circumference, tricipital skin fold and percent body fat. All results in men and women fell within reference values, except for arm circumference in men. The

Table 4. Comparison of the BIA components with the nutritional status of patients on CHD.

	Normal n = 27 (mean ± SD)	Mild malnutrition n = 31 (mean ± SD)	Moderate malnutrition n = 10 (mean ± SD)	Severe malnutrition n = 8 (mean ± SD)	p*
Age (y)	46.62 ± 15.15	47.9 ± 16.34	45.2 ± 21.73	45 ± 15.58	0.953
Height (cm)	155 ± 7.8	159.38 ± 8.94	160 ± 9.45	156.25 ± 9.49	0.243
Weight (kg)	64.4 ± 9.7	63.54 ± 9.44	58.27 ± 13.38	47.02 ± 9.86	0.000
BMI (kg/m^2)	26.6 ± 3.1	24.9 ± 2.73	22.5 ± 3.34	19.1 ± 2.68	0.000
R (Ω)	586.20 ± 117.88	573.04 ± 96.45	533.42 ± 128.57	460.47 ± 50.96	0.026
Xc (Ω)	60.88 ± 17.34	55.98 ± 16.40	42.6 ± 17.01	38.00 ± 20.86	0.002
R/H (Ω/m)	380.7 ± 87.42	361.58 ± 71.20	335.00 ± 88.08	296.64 ± 46.22	0.049
Xc/H (Ω/m)	39.44 ± 11.87	35.19 ± 10.56	26.7 ± 10.63	24.12 ± 13.05	0.002
PA (°)	5.95 ± 1.28	5.56 ± 1.37	4.44 ± 0.96	3.68 ± 1.90	0.000

*one way ANOVA Dunnett's C, SD = standard deviation, R(Ω) = resistance at 50 kHz, Xc(Ω) = reactance at 50 kHz, R/H = resistance/height (Ω/m), Xc/H (Ω/m), = reactance/height , PA(°) = phase angle.

mean BMI values in men and women were also within normal limits. A possible explanation for this result is that patient weight was altered (owing to the frequent overhydration state of this population). It is also interesting that BMI did not correlate with any of the studied variables. These findings were consistent with those of Chertow et al. [4], who found that BMI had no correlation with biochemical indicators or with BIA. They concluded that traditional BIA methods were insensitive to changes in CHD patient body composition. Data on body composition in men and in women, obtained by electric bioimpedance analysis before and after the HD session, showed no significant changes in percentage of fat and lean body mass or in TBW. Traditional BIA methods appear to indicate that body fat percent increased, although not significantly, in post-HD measurements (i.e., after liquid extraction). Several other studies have used BIA to estimate body composition in CHD patients [9, 10]. However, when tissue hydration varies, conventional BIA methods generate inexact compartmental estimations. In the present study, BIA revealed a gain in patient body fat at the end of HD.

Estimation of TBW with the conventional BIA approach uses regression equations based on H^2/R and other variables, including age, gender, body weight and reactance. BIA estimation of masses and volumes of body compartments are accurate in healthy adults, although with 95% prediction intervals > 3 kg. In order to increase the accuracy of TBW and body cell mass estimation from BIA, specific prediction equations have been developed for CHD patients. Unfortunately, these equations result in a bias on the order of 4 – 5 kg with respect to reference methods. Although this is not always true, recently, in an intent to validate bioimpedance analysis prediction equations for dry weight in hemodialysis patients, authors find excellent associations between predicted and measured body weight of 0.3 ± 1.0 kg ($p = 0.03$) with conventional BIA, however this new equation still needs external validation [2]. The pitfalls of conventional BIA, shown in Tables 2 and 3, including phase angles that increase with ultrafiltration (UF) may be explained by inherent assumptions about body geometry, hydration status or the electric model of cell membranes that are erroneously applied in overhydrated patients [19]. Moreover, contrary to the literature indications, the interpretation of PA values should not be made independently of vector magnitude (that is, the Xc and R values) because R and Xc are correlated in living anisotropic tissues and both impedance components are dependent on tissue structure. Our results are consistent with studies published previously [17, 18, 19] where vector displacements (shortening and lengthening) parallel to the major axis of TE indicated changes in tissue hydration (hyperhydration and dehydration) with preserved tissue structure. Vector displacements following different trajectories (that is with greater or lesser phase angles and vector length) indicate combined changes in

tissue structure and hydration. The patterns of vector distribution in CHD patients are expected to be consistent before and after fluid removal (i.e., wet to dry) [18].

The results of the SGA analysis showed that the nutritional state of most of the studied population was different from data reported by other Mexican studies because 68% of the patients were within normal limits, and only a small percentage showed severe malnutrition by this methodology. However, it is important to point out that SGA is a method with a very large error margin. The nutritional status was also evaluated by the mBNI. This index has proved to be a simple and practical tool, which allows for rapid evaluation [3]. Our results showed similarities with those of other studies, demonstrating that most patients had some degree of malnutrition (64%), with only 11% showing severe malnutrition, 13% moderate malnutrition and 40% mild malnutrition. This type of evaluation is of interest because it may help to avoid further nutritional deterioration in HD patients. The vector-BIA method is an immediate, beside, graphic method that can measure the direct correlation between R and Xc in the patient. This can be useful to identify, monitor, and plan ultrafiltration in patients on CHD. At present, it is the only non-invasive technique capable of specifically evaluating hydration variations in almost any clinical condition [10].

Pre- and post-HD results using vector-BIA clearly show that apparent volume overload persists in many patients (men and women) even after the HD session in the clinical absence of edema. This could indicate that a good number of patients are not at their dry weight even after their HD session.

The present study also found an important relationship between overhydration by vector-BIA and degree of malnutrition (by Bilbrey measurement) as shown in Figure 1c. This correlation further supports the importance of close monitoring of the patient's nutritional and volume status, which can be effectively evaluated and sequentially monitored following individual patients' RXc graphs over time.

Correlation analyses of Scr levels and vector-BIA revealed that more magnitude of malnutrition and overhydration were present in both men and women with lower Scr levels, (i.e., the lower the Scr, the higher the rates of overhydration and cachexia). Hypoalbuminemia also strongly correlated to higher morbidity and mortality. In the present study, hypoalbuminemia (3.5 g/dl) and vector-BIA results were strongly correlated in women with volume overload and cachexia. No statistical significance was found in men, perhaps due to the small number of male patients with hypoalbuminemia.

Similar to previous studies by Pillon et al. [19], we found that patients with diabetes mellitus (DM) present with shorter vectors than similar nondiabetic patients. A diabetic patient undergoing HD may be volume overloaded and may have worse nutritional status than a non-DM patient.

Earlier studies have compared vector-BIA to conventional BIA for prescription of optimal dry weight in HD. They have reported that the estimation of the hydration status with conventional BIA was poor, and that vector-BIA is better correlated with clinical symptoms [9]. HD patients often present persistent volume overload, even after their HD session. In a large population of HD patients, Pillon et al. found that there is a significant association between vector length and mortality independent of laboratory values and phase angle, validating the clinical observation linking longevity to maintenance of dry body weight [19].

We present the first study to our knowledge to use vector-BIA assessments of body composition, including nutritional status and volume, and compare them to a standard nutritional index score and other conventional methods of body composition in a large group of CHD patients. We conclude that a combination of traditional nutrition methods and vector-BIA may offer information that can help plan timely interventions to modify HD prescriptions in a patient that may be malnourished and/or overhydrated. This type of active intervention may favorably impact the hemodynamic condition and cardiovascular risk profile of HD patients. Since HD population norms of vector distribution, including length and phase angles, have been developed, vector-BIA may be used to evaluate the adequacy of ultrafiltration in HD patients. In addition to the demonstrated benefit of vector-BIA determinations, this technology is easy to apply, is reasonably priced, and allows for immediate and straightforward estima-

tions of the nutritional and hydration status of the patient on HD. In our study, CHD patients that were classified as malnourished according to mBNI, tended to be hyperhydrated according to vector-BIA. This may have future implications with respect to the risk for cardiovascular morbidity.

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