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A systematic evaluation of bioelectrical impedance measurement after hemodialysis session

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Background. There is still no definitive indication about the ideal point of time to perform bioimpedance analysis (BIA) in hemodialysis patients. Furthermore, the interpretation of data in this regard is difficult because there is still no comprehensive information about the fluctuations in BIA variables occurring in these subjects. The aim of this study was to assess BIA changes occurring in hemodialysis and specifically in the dry-weight state.

Methods. We studied 27 anuric patients (20 males and 7 females; age 56.1 ± 13.7 years) on chronic hemodialysis. Single-frequency BIA (R, resistance; Xc, reactance; and PhA, phase angle) was performed (*1*) before and at the end of hemodialysis (dialysis period); (*2*) 15, 30, 60, 90, and 120 minutes after hemodialysis (postdialysis period); and (*3*) 24, 48, and 68 hours after hemodialysis (interdialysis period).

Results. Body weight decreased by 2.8 ± 0.8 kg during hemodialysis, was unchanged during the postdialysis period, and progressively rose during the interdialysis period. At the same time, BIA variables significantly increased during hemodialysis (R, 453 ± 74 and 542 ± 98 ohm; Xc, 38 ± 10 and 53 ± 16 ohm; $P < 0.05$), remained stable over the 120-minute period after treatment (R, 538 ± 94, 539 ± 95, 538 ± 94, 541 ± 95, and 544 ± 95 ohm; and Xc, 53 ± 15, 53 ± 15, 51 ± 16, 52 ± 16, and 52 ± 16 ohm; NS), and subsequently declined [R, 471 ± 79 ($P = <0.05$ vs. postdialysis), 449 ± 71 ($P = <0.05$ vs. postdialysis), 424 ± 68 ($P = <0.05$ vs. postdialysis) ohm; Xc, 42 ± 13 ($P = <0.05$ vs. postdialysis), 37 ± 10 ($P = <0.05$ vs. postdialysis), 34 ± 13 ($P = <0.05$ vs. postdialysis) ohm]. The stability of BIA measures during postdialysis was confirmed by the constant relationship found between R/height and Xc/height. Also PhA increased after dialysis (4.8 ± 1.1 degrees vs. 5.7 ± 1.3 degrees, $P < 0.05$), was unchanged during the following 120 minutes and decreased in the interdialysis period (5.1 ± 1.3 degrees, 4.8 ± 1.0 degrees, and 4.5 ± 1.1 degrees, $P < 0.05$). At the end of hemodialysis and during the postdialysis period total body water (TBW) estimated from BIA was similar on average to TBW calculated using Watson formulas (37.2 ± 6.3 L vs. 36.2 ± 5.7 L, NS). On the contrary, when patients were hyperhydrated BIA significantly overestimated the Watson's values.

Conclusion. In hemodialysis patients BIA variables fluctuate to a considerable extent (with the highest values immediately after hemodialysis), but remain constant and highly reproducible over the 120 minutes after the end of hemodialysis, that is, in a dry-weight state. Thus, taking into consideration that the point in time chosen for performing BIA is crucial to properly assess body composition, BIA can be appropriately performed at anytime during the postdialysis period, provided that hydration status does not change due to food or drink consumption.

Key words: bioelectrical impedance analysis, BIA, resistance, reactance, phase angle, body water, hemodialysis.

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Single-frequency bioelectrical impedance analysis (BIA) is a safe, noninvasive, rapid, and inexpensive technique, which evaluates some basic electrical properties of the body by measuring resistance (R), reactance (Xc), and phase angle (PhA). In healthy and ill individuals total body water (TBW) and fat-free mass can be estimated using formulas that include BIA variables and often also individual's general characteristics [1]. As an alternative, BIA values are evaluated as such in comparison to reference values obtained in the general population (as R and Xc percentiles, or bivariate R-Xc confidence limits). Well-standardized conditions are needed to improve the accuracy of such a technique with regard to electrode placement, patient's positioning, hydration status, food or beverage assumption, environmental temperatures, etc. [2–4]. Specifically, in patients undergoing hemodialysis BIA should be determined on the nonaccess side, since the presence of a functioning arteriovenous fistula reduces R to a substantial extent [4–6].

BIA has attracted the nephrologists' attention because of its ease of use and the opportunity to evaluate both nutritional status and hydration. Indeed, in hemodialysis patients single-frequency BIA is expected to be affected and maybe distorted by changes in total as well as extracellular water, in particular if taking place in a short time [7, 8]. Although in theory it should be performed in a dry-weight condition (i.e., after excess fluid removal), there is still neither convincing indications nor agreement about the point of time to perform BIA in hemodialysis patients.

As a matter of fact some authors carried out BIA before hemodialysis [9–11], others at the end or during the immediate postdialysis period [12–14], and some others on the day between two dialysis sessions [15]. Furthermore, the interpretation of data in this regard is difficult because there is still no comprehensive information about the fluctuations in BIA variables occurring in hemodialysis patients.

The purpose of this study was therefore to assess in a systematic way the changes in BIA variables occurring in hemodialysis. A particular interest was placed on the period that immediately follows the end of hemodialysis treatment, in order to establish whether BIA measures are stable and reproducible in the dry-weight condition.

METHODS

Patients

Twenty-seven anuric patients (20 males and 7 females; age 56.1 ± 13.7 years) on chronic hemodialysis treatment (standard bicarbonate hemodialysis at a thrice weekly regimen) for at least 6 months (dialysis duration 87 ± 69 months) participated in the study after giving their informed consent to the experimental protocol. The dialysis access was always an arteriovenous fistulas in the distal left forearm. In the 6 months before the study the patients did not have any acute illnesses while their dry-weight (measured at the end of the third dialysis session of the week) was stable (changes <1%). In addition, no patients had edema, as assessed by clinical or instrumental evaluation (chest and abdomen x-ray or ultrasound examination).

Study protocol

BIA was performed at the last dialysis session of week in (*1*) the dialysis period, immediately before (predialysis) and at the end of hemodialysis; (*2*) the postdialysis period, 15, 30, 60, 90, and 120 minutes after hemodialysis; and (*3*) the interdialysis period, 24, 48, and 68 hours after hemodialysis. During both dialysis and postdialysis, patients were not allowed to drink or eat. Body weight was always measured using a bed balance with a scale of 0.05 kg (Tassinari, Cento-Italy).

Single-frequency BIA was conducted by the same operator using a BIA 101-S plethysmograph (injecting 800 μA and 50 kHz alternating sinusoidal current) (RJL/Akern System, Florence, Italy). Measurements were carried out on the nonaccess side of the body in standardized conditions [7] (quiet environment, ambient temperature 22 to 24°C after the patient was laying for at least 30 minutes), to remove potential causes of bias [4–6]. With regard to the placement of electrodes, an inner sensing electrode was attached on the dorsal surface of the patient's wrist and an outer source electrode placed on the dorsal surface of the third metacarpal bone, the second pair of electrodes being positioned on the anterior surface of the ankle and the third metatarsal bone, respectively. The electrodes were left on place from predialysis to the end of postdialysis period, with the connection to the device disrupted after each measurement.

Table 1. Patients characteristics

Patients *number*	27
Males/females *number*	20/7
Age *years*	56.1 ± 13.7
Dialysis age *months*	87 ± 69
Body weight *kg*	67.9 ± 12.0
Height *cm*	162 ± 8
Body mass index *kg/m²*	25.8 ± 4.6

Calculations

Resistance (R) and reactance (Xc) were considered as such or indexed to height (R/H and Xc/H). TBW was estimated using either the BIA equation of the instrument's software (TBW-BIA) [16] or Watson equations (TBW-W) [17]. TBW-BIA was determined from measured values for each experimental time. TBW-W was first calculated in the dry-weight condition (i.e., immediately after hemodialysis session) according to the following formulas: $2.447 - (0.09156 * \text{age}) + (0.1074 * \text{height}) + (0.3362 * \text{weight})$ for males, and $[-2.097 + (0.106 * \text{height}) + (0.2466 * \text{weight})]$ for females. The estimates for the other points of time were derived from dry-weight values and weight changes, assuming that the latter were due entirely to TBW variations.

Statistical analysis

Data were expressed as mean ± standard deviation (SD). Intragroup comparisons were performed using paired Student *t* test or analysis of variance (ANOVA) for repeated measures followed by the Bonferroni post hoc test. Unpaired Student *t* test was used for intergroup comparisons. TBW-BIA was compared to TBW-W using regression analysis and Bland-Altman plots [18] based on between-method differences. In particular, the differences were plotted against the mean BIA-W value, in order to evaluate if the differences are influenced by the magnitude of TBW, and the 95% limits of agreement (including 95% of the between-method differences) were determined. A P value < 0.05 was considered statistically significant.

RESULTS

The characteristics of the patients enrolled for the study are summarized in Table 1. During the 3 months prior to

Table 2. Body weight and bioelectrical impedance analysis (BIA) measures before and after the hemodialysis session and during the post- and interdialysis periods

Time	Body weight *kg*	Resistance *ohm*	Reactance *ohm*
Start of dialysis	70.7 ± 12.3	453 ± 74[a]	38 ± 10[a]
End of dialysis	67.9 ± 12.0	542 ± 98	53 ± 16
Postdialysis			
15 minutes	67.9 ± 12.0	538 ± 94	53 ± 15
30 minutes	67.9 ± 12.0	539 ± 95	53 ± 15
60 minutes	67.9 ± 12.0	538 ± 94	51 ± 16
90 minutes	67.9 ± 12.0	541 ± 95	52 ± 16
120 minutes	67.9 ± 12.0	544 ± 95	52 ± 16
Interdialysis			
24 hours	69.3 ± 12.3	471 ± 79[a]	42 ± 13[a]
48 hours	70.5 ± 12.3	449 ± 71[a]	37 ± 10[a]
68 hours	71.3 ± 12.5	424 ± 68[a]	34 ± 10[a]

[a] $P < 0.05$ vs. end of dialysis.

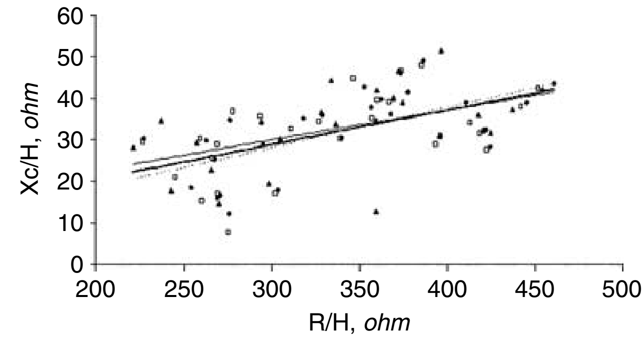

Fig. 1. Simple correlation between resistance/height (R/H) and reactance/height (Xc/H). This correlation was measured at the end of dialysis (▲) ($R^2 = 0.249$), and at 60 (□) ($R^2 = 0.307$), and 120 minutes (•) ($R^2 = 0.406$) during the postdialysis period.

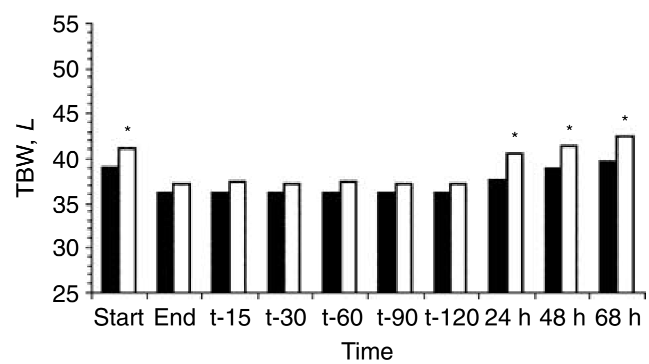

Fig. 2. Total body water (TBW) calculated with Watson's formula (■) and measured by bioelectrical impedance assay (BIA) (□) prior to (start) and after (end) the hemodialysis session and during the post- (t) and interdialysis (h) periods. *$P < 0.001$ vs. Watson.

the study all the patients had both normal serum levels of C-reactive protein and albumin, and constant values of dry-weight.

Table 2 shows the changes in body weight and BIA variables occurring during the entire experimental period. Body weight decreased by 2.8 ± 0.8 kg (−4.1 ± 1.0% of predialysis values) during hemodialysis while it remained stable over the 120-minute period after the end of treatment. Subsequently, weight gain was 1.4 ± 0.6 kg at 24 hours, 2.6 ± 0.8 kg at 48 hours, and 3.4 ± 0.9 kg at 72 h after hemodialysis. In general terms, R and Xc significantly increased during dialysis and declined during the following days. However, BIA measures were very stable during the 120 minutes following hemodialysis, the coefficient of variation on serial measurements being 1.6% for R and 2.2% for Xc. PhA, which markedly increased after dialysis session (4.8 ± 1.1 degrees vs. 5.7 ± 1.3 degrees, $P < 0.05$), also remained constant during the subsequent 120 minutes (5.7 ± 1.3 degrees at 15 minutes, 5.6 ± 1.2 degrees at 30 minutes, 5.5 ± 1.5 degrees at 60 minutes, 5.5 ± 1.5 degrees at 90 minutes, and 5.6 ± 1.3 degrees at 120 minutes), with a mean coefficient of variation of 1.2% and a maximum variation of 0.3 degrees. On the contrary, PhA decreased ($P < 0.05$) in the interdialysis period (5.1 ± 1.3 degrees at 24 hours, 4.8 ± 1.0 degrees at 48 hours, and 4.5 ± 1.1 degrees at 72 hours). The stability of BIA measures over the 120 minutes after hemodialysis was also confirmed by considering the regressions between R/H and Xc/H which were very similar to each other for measures taken immediately after hemodialysis or during the postdialysis period (Fig. 1).

The estimates of TBW given by the instrument's software (TBW-BIA) were compared to the ones calculated using Watson equations (TBW-W). The linear correlations between TBW-BIA and TBW-W was very significant at different points of time (before hemodialysis, $r = 0.828$, $P < 0.0001$; immediately after hemodialysis, $r = 0.812$, $P < 0.0001$; 24 hours after hemodialysis, $r = 0.823$, $P < 0.0001$; and 68 hours after hemodialysis, $r = 0.825$, $P < 0.0001$). As shown in Figure 2, at the end of hemodialysis TBW-BIA was on average quite close to TBW-W [37.2 ± 6.3 L (55.5 ± 8.0% body weight) vs. 36.2 ± 5.7 L (53.8 ± 5.5% body weight), $P = 0.147$] with a difference of only 1.0 ± 3.2 L. A similar discrepancy was also observed over the 120-minute postdialysis period. On the contrary, when patients were hyperhydrated, TBW-BIA was always significantly higher ($P < 0.005$) than TBW-W, by 2.6 ± 4.0 L, in predialysis, and 2.2 ± 3.8 L, and 3.1 ± 3.8 L at 24 and 68 hours after hemodialysis, respectively. On the other hand, the Bland-Altman analysis (Fig. 3) indicated that the between-method differences were not influenced by the mean magnitude (for BIA and Watson) of TBW, while the 95% limits of agreement were +9.9/−5.5 L in predialysis, +7.4/−5.4 L in postdialysis, and +10.6/−5.4 L at 24 hours, and +10.8/−4.6 L at 68 hours after hemodialysis.

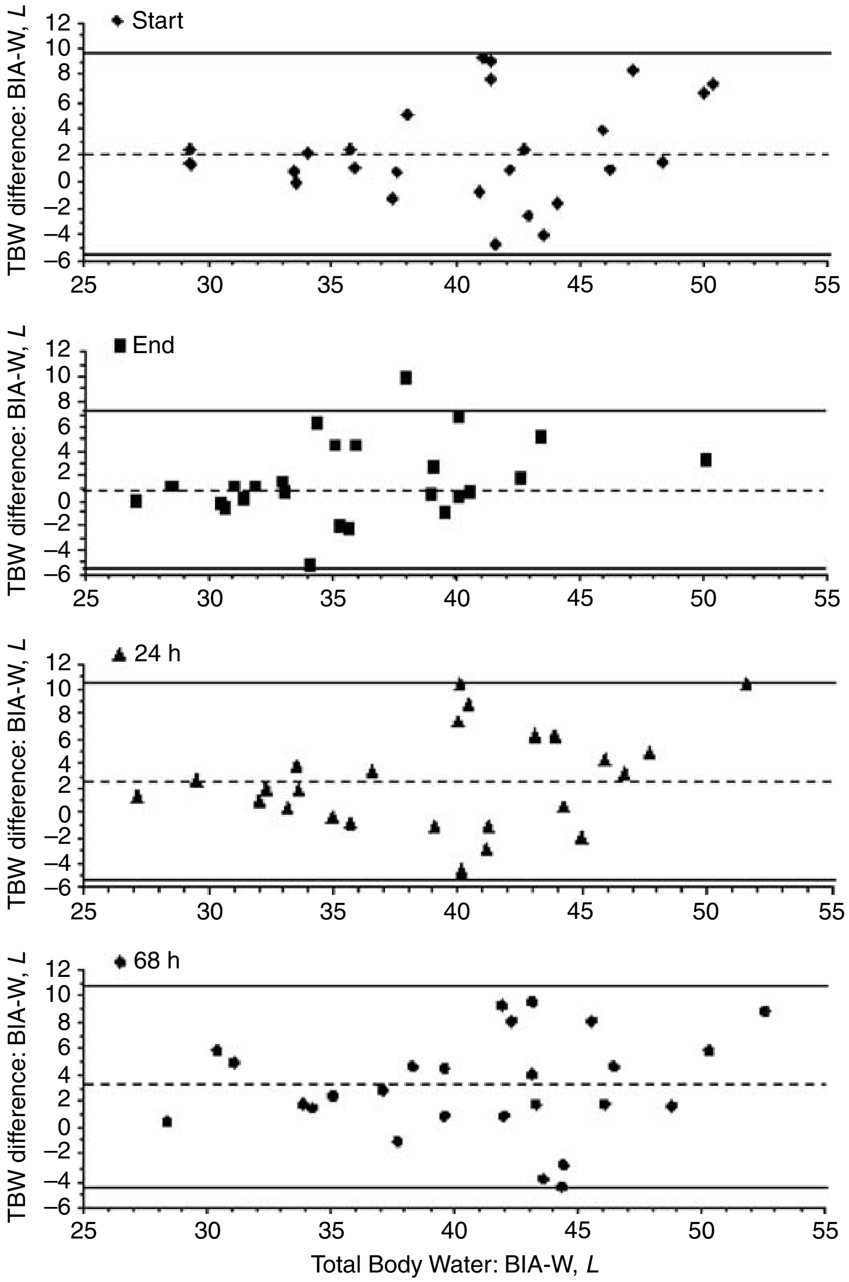

Fig. 3. Bland-Altman plot between total body water (TBW) measured by bioelectrical impedance assay (BIA) and calculated with Watson's formula (W), prior to (start) and after (end) hemodialysis session, and at 24 hours and 68 hours during the interdialysis time. Dotted lines represent the between method differences and solid lines the 95% difference interval.

DISCUSSION

The present paper yields some comprehensive and systematic data on changes in bioelectrical variables occurring in hemodialysis patients immediately after the end of treatment (postdialysis period) and in the following 3 days (interdialysis period).

The accuracy of BIA can substantially be improved if well-standardized measurement conditions are ensured [2]. Indeed, it is well known that single-frequency BIA reflects variation in TBW and the ratio between extracellular water and TBW. This is a crucial point when hemodialysis patients are taken into consideration because they undergo cyclic changes in hydration (no steady-state condition). In this case, the maximum volume expansion is reached just before hemodialysis; thereafter, TBW rapidly decreases during hemodialysis to achieve the lowest value at the end of treatment (with no change in the immediate following period until fluid intake is restored), and then progressively increases during the interdialysis period [13, 14]. Our data indicate that at the same time R, Xc, and PhA fluctuate to a quite large extent. As already observed [14], an increase in each of these variables, which was more marked for Xc, was observed after hemodialysis. Thereafter, there was a progressive decline in both R and Xc until the next dialysis session. Indeed, 24 hours after dialysis BIA variables were still considerably different from predialysis values (+4% for R and +10.5% for Xc) while no difference was detected after 48 hours (Table 2).

From a practical point of view, in studies on hemodialysis patients BIA has been determined either just before dialysis or at different points of time (30 to 90 minutes) after the end of treatment [11–14, 16], or in nondialysis day (i.e., 24 hours after treatment). Thus, there is neither specific indication nor general agreement about the most appropriate time to perform BIA and different points of time are expected to correspond to different hydration states. Our data clearly indicate that measures at different times are not comparable, and significant differences were apparent not only between the measures obtained just before and immediately after hemodialysis, but also when those recorded 24 hours after treatment were taken into consideration. This point is crucial to properly assess differences between hemodialysis patients and controls and for the comparison with reference normal percentiles or bivariate R-Xc confidence limits, etc. Furthermore, as PhA is considered an independent marker of survival in end-stage renal disease (ESRD), also the prognostic value of such a parameter would be influenced by the point of time chosen for BIA [13, 19–21].

More specifically, it is of interest to evaluate BIA when patients reach their dry weight after excess fluid removal (postdialysis period). Some uncertainties with regard to this approach come up from the fact that in theory the sudden hydrosaline and osmotic changes as well as the loss of extracellular water occurring during hemodialysis, can perturb BIA measures; as a matter of fact, it is well known that BIA changes do not accurately predict water loss during hemodialysis. This point, however, has never been systematically explored. Our data indicate that after hemodialysis an increase in R (on average +12%) was observed which was disproportionate to the decrease in body weight (−4%) but also demonstrate that BIA measures were highly reproducible over the 120-minute period after the end of hemodialysis. Thus, BIA can be performed anytime during the 2 hours after treatment and constant results are expected, provided that hydration status does not change (no drinks or food allowed). Moreover, our results do not support the idea that postdialysis plasma solute rebound, associated with an intra- to extracellular water shift, can immediately affect BIA measurements.

Finally, we compared the estimates of TBW obtained with the software provided with the BIA instrument (according to [16]) with the estimates calculated using Watson equations. These formulas were demonstrated to yield a reasonable measures of TBW in hemodialysis patients in the dry-weight condition [22]. On average the agreement between the two methods was quite good in the postdialysis period, and worse in the predialysis and in the interdialysis period when BIA significantly overestimated the Watson estimates. Thus, a further finding of the present paper was that BIA, at least on average, resulted to reasonably predict TBW in the dry-weight state, but to overestimate it in over-hydrated condition.

CONCLUSION

In hemodialysis patients BIA variables fluctuate to a considerable extent with the highest values observed immediately after the end of dialysis. R, Xc and PhA at 24 hours after treatment are still significantly different in comparison with predialysis values. On the other hand, BIA variables remain constant over the 120 minutes after the end of dialysis (dry-weight state). Over this period BIA allows reproducible measures of PhA and gives estimates of TBW which are similar to those derived using Watson equations. Thus, taking into account that the point in time chosen for performing BIA is crucial to properly assess differences between hemodialysis patients and controls and to identify abnormal values by using reference normal percentiles or ellipses, BIA can be appropriately performed at anytime during the postdialysis period, provided that hydration status does not change due to food or drink consumption.

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