Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/medici

Original Research Article

Evaluation of fluid status related parameters in hemodialysis and peritoneal dialysis patients: Clinical usefulness of bioimpedance analysis

Zülfükar Yılmaz [a,*], *Yaşar Yıldırım* [a], *Fatma Yılmaz Aydın* [b], *Emre Aydın* [b], *Ali Kemal Kadiroğlu* [a], *Mehmet Emin Yılmaz* [a], *Halit Acet* [c]

[a] *Department of Nephrology, Faculty of Medicine, Dicle University, Diyarbakır, Turkey*
[b] *Department of Internal Medicine, Faculty of Medicine, Dicle University, Diyarbakır, Turkey*
[c] *Department of Cardiology, Faculty of Medicine, Dicle University, Diyarbakır, Turkey*

ARTICLE INFO

Article history:
Received 30 April 2014
Accepted 25 September 2014
Available online 1 November 2014

Keywords:
Hemodialysis
Peritoneal dialysis
Bioimpedance analysis

ABSTRACT

Background and objective: Fluid overload is a common and serious problem that leads to severe complications in dialysis patients. We aimed to compare hydration status as measured with bioimpedance analysis (BIA) method in hemodialysis (HD) and peritoneal dialysis (PD) patients, as well as investigating the association between blood pressure, left ventricular mass index (LVMI) and hydration status.

Materials and methods: We examined 43 HD and 33 PD patients. Blood pressure was recorded. In each group, echocardiographic examinations were performed on all patients. Hydration status was assessed using multifrequency bioelectrical impedance analysis. Overhydration was defined as an overhydration (OH)/extracellular water (ECW) ratio of >0.15.

Results: The OH/ECW ratio was significantly higher in PD patients compared to post-HD patients. Overhydration was statistically more frequent in PD than in post-HD patients (30.3% vs. 11.6%, $P = 0.043$). Systolic blood pressure (SBP) in both post-HD and PD groups, and LVMI in the PD group were found to be significantly higher in overhydrated patients than non-overhydrated patients. In multiple linear regression analyses, increased OH/ECW ratio was independently associated with higher SBP and LVMI.

Conclusions: Fluid overload may be an even more prevalent and serious problem in PD patients. Overhydration is closely associated with increased blood pressure and LVMI. OH/ECW ratio, a derived parameter of fluid load measured by BIA, was a significant and independent determinant of SBP and LVMI.

* *Corresponding author at*: Department of Nephrology, Faculty of Medicine, Dicle University, 21280 Diyarbakır, Turkey.
E-mail address: drzulf21@gmail.com (Z. Yılmaz).

Peer review under responsibility of the Lithuanian University of Health Sciences.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.medici.2014.10.007

1. Introduction

Fluid overload is a common and serious problem that leads to severe complications in hemodialysis (HD) and peritoneal dialysis (PD) patients. Cardiovascular diseases (CVD) are the leading cause of morbidity and mortality in end-stage renal disease (ESRD) patients [1]. Volume and pressure overload have an important impact on development of cardiovascular disease. It is known that fluid overload is clearly associated with hypertension and left ventricular hypertrophy in this population. However, management of hypertension is difficult in dialysis patients, and many patients also have uncontrolled hypertension despite the use of antihypertensive drugs [2]. Moreover, better control of blood pressure requires accurate fluid balance in most dialysis patients.

In addition, it is also shown that fluid overload is associated independently and significantly with mortality in dialysis patients [3,4]. Euvolemia is most commonly evaluated based on unreliable clinical signs, such as changes in body weight, edema and blood pressure, in daily clinical practice by the dialysis provider, but those may lead to misinterpretations. Therefore, more reliable, practical and objective methods are extremely needed. In this respect, bioelectrical impedance analysis (BIA) has been proposed for the assessment of hydration status parameters.

BIA is a simple, safe, novel, rapid, noninvasive and promising method that can be used to determine hydration status in patients on dialysis therapy [5–8]. BIA method has gained increasing popularity in recent years. Different from other methods, it allows quantification of intracellular and extracellular volumes [9]. The Body Composition Monitor (BCM, Fresenius Medical Care, Germany) is a bio-impedance spectroscopy device and has been well validated by gold standard methods for clinical use [5,6].

In the present study, we aimed to compare hydration status, as measured with BIA method, in HD and PD patients in a single center, as well as investigating the association between blood pressure, left ventricular mass index (LVMI) and hydration status.

2. Materials and methods

2.1. Patients

This cross-sectional study design included 43 stable chronic hemodialysis and 33 stable chronic ambulatory peritoneal dialysis (CAPD) patients treated and followed up in the same center. The Local Human Research Ethics Committee approved the study protocol, and informed consent was obtained from all patients at the time of study enrollment.

The exclusion criteria were as follows: (1) patients with ejection fraction <55%, (2) hemodynamically unstable patients, (3) patients who had limb amputation, pacemakers, or metallic intravascular devices, or any malignant disease or pregnancy, (4) patients who had been receiving diuretic treatment.

The HD patients received dialysis 3 times/week, using 1.6 m^2 surface area high-flux polysulphone dialyzers (Fresenius, Bad Homberg, Germany) and bicarbonate-based dialysate (glucose 1 mmol/L, Na^+ 140 mEq/L, HCO_3^- 32 mEq/L, K^+ 2.0 mEq/L, Ca^{2+} 1.25 mmol/L, Mg^{2+} 0.5 mEq/L). Of the 33 patients on CAPD, icodextrin was administered in 65% of them.

Patients' demographics were obtained from both the patients' registries and the patients themselves.

2.2. Measurements

24-h urine samples were collected to determine urine volume. Weight was measured after dialysis. Body mass index (BMI) was calculated as the ratio weight/height^2 (kg/m^2) and body surface area (BSA) was calculated from weight and height.

Systolic (SBP) and diastolic blood pressures (DBP) were measured 30 min after the end of hemodialysis using an air manometer at the time of BIA investigation and are presented as three consecutive measurements taken at 5-min intervals. Blood pressures were measured in PD patients with empty abdomen using the same method.

Blood samples were collected from all patients for biochemical and hematological parameters on the same day as the BIA measurements.

2D-guided M-mode echocardiography (Vivid 7, GE Healthcare, Horten, Norway) with a 3.5 MHz transducer was performed with empty abdomen in all PD patients, and after the hemodialysis session in all HD patients, by the same cardiologist according to the recommendation of the American Society of Echocardiography on the same day as the BIA examination [10]. Left ventricular systolic function was assessed by left ventricular ejection fraction (LVEF). Left ventricle internal diastolic diameter (LViDD), diastolic posterior wall thickness (PWT) and interventricular septum thickness (IVS) were measured. Left ventricular mass (LVM) was calculated using the equation described by Devereux [11].

$$LVM = 1.04 \times [(LviDD + PWT + IVS)^3 - LviDD^3] - 13.6\,g$$

sLVM index (LVMI) was calculated by dividing LVM by BSA.

A multifrequency BIA device (Body Composition Monitor, BCM, Fresenius Medical Care D GmbH), which measures 50 different frequencies from 5 to 1000 kHz, was used to assess hydration status. All measurements were performed by the same operator. BIA was performed with empty abdomen in PD patients, and 30 min after the midweek dialysis session in HD patients. The following parameters were obtained: overhydration (OH), extracellular water (ECW), intracellular water (ICW), total body water (TBW) in liters (L), ECW/TBW, ECW/ICW, and OH/ECW ratio. We used OH/ECW ratio as an indicator of fluid status. Overhydration was defined as an OH/ECW ratio greater than 0.15 according to previous reports [3,12]. Patients were divided into two groups: overhydrated (OH/ECW >0.15) and nonoverhydrated (OH/ECW ≤0.15).

2.3. Statistical analysis

Data analyses were performed using Statistical Package for Social Sciences (SPSS), Version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). Normally distributed variables are presented using means and standard deviations. The Student *t* test was used to compare the means of the continuous variables with normal distribution for related and independent samples. The proportions of patients with overhydration are presented

using cross tabulations between groups. The chi-square test was used to compare these proportions in different groups. The Pearson correlations were used for simple regression analysis. A multiple linear regression analysis was performed to identify independent predictors of SBP and LVMI. *P* values less than 0.05 were considered statistically significant.

3. Results

A total of 76 dialysis patients (43 post-HD and 33 PD) were enrolled in the study. The baseline demographic, clinical, relevant laboratory data and BIA parameters are presented in Table 1.

PD patients were younger than HD patients. There were no significant differences in gender distribution and dialysis vintage between groups. The patients on PD had significantly higher residual urine and lower percentage of diabetes than patients on HD. SBP and DBP were lower in post-HD compared to PD patients. Left ventricular ejection fraction was significantly lower in the PD group than in the post-HD group.

Regarding the derived parameters of BIA, OH and OH/ECW ratios were higher in PD group compared to the post-HD group. Overhydration based on OH/ECW was statistically more frequent in PD than in post-HD patients (30.3% vs. 11.6%, $P = 0.043$).

Five patients in the post-HD group and 10 patients in the PD group were significantly overhydrated (OH/ECW >0.15). Overhydrated patients had significantly higher SBP in both post-HD and PD groups (HD: 123.33 ± 19.14 vs. 109.86 ± 13.46, $P = 0.038$; PD: 148.88 ± 22.60 vs. 122.50 ± 21.11, $P = 0.004$; Fig. 1A) than non-overhydrated patients. However, there were no significant differences in terms of diastolic blood pressure between overhydrated patients and non-overhydrated patients both in the post-HD and the PD groups (Fig. 1B). Compared to non-overhydrated patients, overhydrated patients had significantly higher levels of LVMI in the PD group (151.23 ± 15.10 vs. 99.50 ± 27.24, $P < 0.001$; Fig. 1C).

There were significant positive correlations between OH/ECW and SBP, DBP, OH, ECW, ECW/TBW, ECW/ICW, and LVMI and negative correlations with albumin and EF (Table 2).

Furthermore, we modeled a stepwise linear regression analysis to define the independent determinants of SBP and LVMI. PD as dialysis modality and increased OH/ECW ratio were independently associated with higher SBP (Table 3). For LVMI, OH/ECW (greater overhydration) was the independent predictor (Table 4).

Table 1 – Demographic, clinical, relevant laboratory data and bioimpendance parameters in hemodialysis vs. peritoneal dialysis patients.

Parameters	post-HD ($n = 43$)	PD ($n = 33$)	*P*
Age, years	51.8 ± 15.8	38.6 ± 15.8	0.001
Gender, M/F, *n*	13/30	11/22	0.77
Dialysis vintage, months (months)	70.6 ± 39.8	75 ± 51.5	0.79
Diabetes, %	25.6	3	0.008
Residual urine, mL/day	29 ± 9	479 ± 70	0.001
Na, mEq/L	136 ± 2	135 ± 2	0.131
Albumin, g/dL	3.3 ± 0.4	3.1 ± 0.4	0.202
Hemoglobin, g/dL	10.9 ± 1.4	12.8 ± 16.6	0.335
SBP, mmHg	111 ± 14	129 ± 24	<0.001
DBP, mmHg	71 ± 9	83 ± 15	<0.001
OH, L	0.6 ± 1.0	1.3 ± 1.2	0.011
TBW, L	28.5 ± 6.9	27.4 ± 5.7	0.52
ECW, L	13.2 ± 3.1	13.4 ± 2.8	0.95
ICW, L	15.2 ± 4.3	14.4 ± 3.0	0.34
ECW/ICW	0.9 ± 0.1	0.9 ± 0.1	0.35
ECW/TBW	0.4 ± 0.05	0.4 ± 0.08	0.23
OH/ECW	0.04 ± 0.07	0.09 ± 0.09	0.009
OH/ECW >0.15, %	11.6	30.3	0.043
LVEF, %	66 ± 4	59 ± 0.8	<0.001
LVMI, g/m^2	106 ± 24	113 ± 33	0.31

SBP, systolic blood pressure; DBP, diastolic blood pressure; OH, overhydration; ECW, extracellular water; ICW, intracellular water; TBW, total body water; LVMI, left ventricular mass index; LVEF, left ventricular ejection fraction; post-HD, posthemodialysis; PD, peritoneal dialysis.

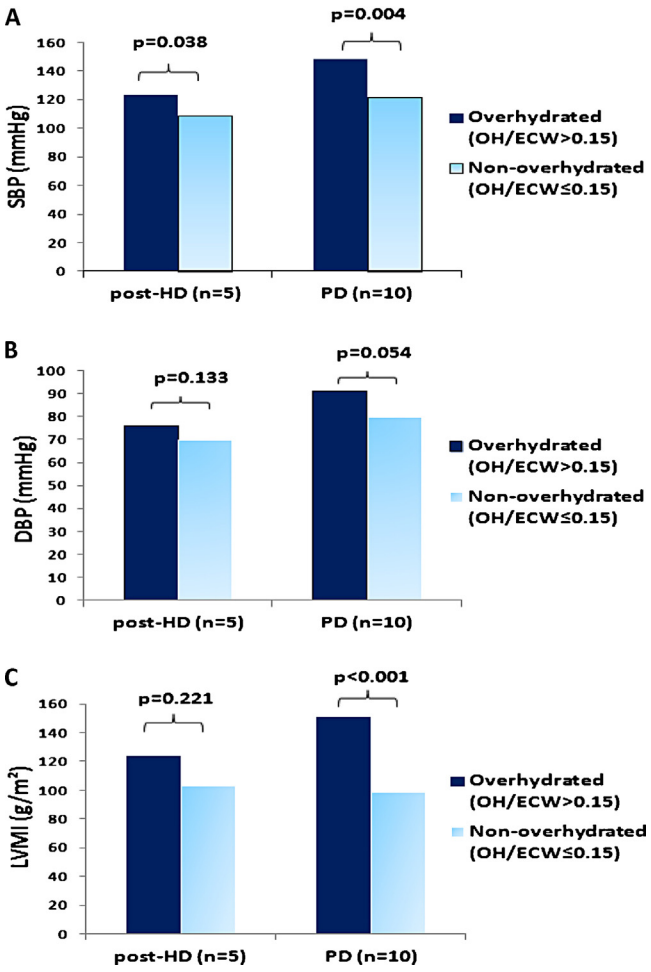

Fig. 1 – Comparison of systolic blood pressure (SBP) (A), diastolic blood pressure (DBP) (B), and left ventricular mass index (LVMI) (C) between overhydrated and nonoverhydrated patients in posthemodialysis (post-HD) and peritoneal dialysis (PD) groups.

Table 2 – Correlations between the overhydration/extracellular water ratio and study parameters.

Variable	r	P
Age	−0.016	0.891
Albumin	−0.291	0.011
SBP	0.519	<0.001
DBP	0.442	<0.001
OH	0.966	<0.001
ECW	0.217	0.059
ICW	−0.227	0.051
TBW	0.029	0.805
ECW/TBW	0.389	<0.001
ECW/ICW	0.597	<0.001
LVMI	0.562	<0.001
EF	−0.338	0.003

SBP, systolic blood pressure; DBP, diastolic blood pressure; OH, overhydration; ECW, extracellular water; ICW, intracellular water; TBW, total body water; LVMI, left ventricular mass index; EF, ejection fraction.

4. Discussion

Fluid overload is frequently present in dialysis patients and leads to adverse clinical outcomes such as hypertension [13], cardiovascular diseases [14,15] and higher mortality [16]; thus, keeping dialysis patients euvolemic is essential [12]. Despite the fact that fluid overload is a preventable or treatable condition, managing fluid balance and achieving true dry weight is still major challenge in both HD and PD patients. The indices obtained from BIA are useful for the assessment of fluid status [17].

The different dialysis modalities, such as peritoneal dialysis and hemodialysis, have different effects on fluid volume control [4]. Although PD is believed to provide better fluid control than HD due to its continuous ultrafiltration and the fact that residual renal function is better maintained [18,19], fluid overload is a quite common problem in PD patients [20]. In the EuroBCM study conducted in six European countries on 639 PD patients, Van Biesen et al. recently reported that severe fluid overload was present in 25.2% of the study population [21]. By BIA measurement, Devolder et al. revealed that the ratio of OH/ECW was higher in the PD patients compared to post-HD patients [12]. In agreement with the findings of Devolder et al., our study has shown that the ratio of OH/ECW was significantly higher in PD patients compared to post-HD patients. Overhydration based on OH/ECW was statistically more frequent in PD than post-HD patients (30.3% vs. 11.6%, $P = 0.043$).

Table 3 – Stepwise multiple linear regression analyses for the independent determinants of systolic blood pressure.

Independent variables	Beta coefficient	95% CI	Standardized Beta coefficient	P
Modality (HD vs. PD)	−9.31	−17.52 to −1.09	−0.225	0.027
OH/ECW	120.14	72.18 to 168.10	0.497	<0.001
Constant	116.01			

CI: confidence interval.
Model: $P < 0.001$; $R^2 = 0.371$.
Included variables: dialysis modality (HD vs. PD), OH/ECW, dialysis vintage, gender (male vs. female) and DM vs. non-DM.

Table 4 – Stepwise multiple linear regression analyses for the independent determinants of LVMI.

Independent variables	Beta coefficient	95% CI	Standardized Beta coefficient	P
OH/ECW	190.69	126.77 to 254.61	0.568	<0.001
Constant	97.17			

CI: confidence interval.
Model: $P < 0.001$; $R^2 = 0.323$.
Included variables: OH/ECW, albumin, gender (male vs. female), HD vs. PD, SBP and DBP.

The findings of this study indicate that fluid overload may be an even more common and serious problem in PD patients compared to HD patients. One of the most important reasons might be that hemodialysis provides easier and more efficient control of extracellular volume overload [22]. Another reason might be that physicians evaluate fluid status of PD patients less frequently than HD patients [23]. Given that fluid overload seems to be frequent in both PD and post-HD patients, it is clear that current methods are insufficient in volume control. In this respect, bioimpedance analysis may be helpful to overcome this issue.

Hypertension is very frequent in ESRD patients and leads to several adverse clinical outcomes [22]. While the pathogenesis of hypertension is multifactorial, fluid overload is the leading cause in dialysis patients [23]. It has been revealed in many studies that increased fluid overload is basically in an extracellular fluid compartment that results in hypertension [24,25]. Chen et al., in a prospective study including 121 HD and 84 PD patients, observed that all patients with overhydration had hypertension in both the hemodialysis and peritoneal dialysis groups [26]. Another study by Yao et al. reported that overhydrated patients assessed by BIA measurement had higher SBP than non-overhydrated ones, in both the PD and the HD patients [27]. Compatible with the findings of Yao et al., overhydrated patients in our study had significantly higher SBP compared to non-overhydrated patients in both post-HD and PD groups. Another important finding of the present study is that an increased OH/ECW ratio and PD as dialysis modality are independently associated with higher SBP in multiple linear regression analyses.

Our study contributes strong support to the previous studies by demonstrating the close association between hydration status and blood pressure. Given the importance of hypertension as the main cause of morbidity and mortality in the dialysis population [23], one of the main goals is to achieve a normotensive state. Although its utility was not investigated in our study design, we believe that BIA can help to distinguish dialysis patients whose hypertension is volume-dependent or non-volume dependent, and can also prevent unnecessary antihypertensive agent using.

Left ventricular hypertrophy (LVH) is very prevalent in ESRD patients at the start of dialysis [28,29]. Increased left ventricular mass (LVM) is associated with mortality and cardiovascular morbidity in this patient population [30]. Despite the fact that several factors, such as anemia, hyperparathyroidism, uremia and malnutrition, play roles in the development of LVH, hypertension and fluid overload are the main causes. The relationship between fluid overload and LVH was revealed in previous reports [13,15]. Consistent with the results of Yao et al. [27], our study has shown that increased an OH/ECW ratio was independently associated with higher LVMI. Moreover, we found that overhydrated patients had significantly higher levels of LVMI in the PD groups compared to non-overhydrated patients. These findings once again emphasize the importance of volume control for cardiac protection in dialysis patients.

5. Conclusions

We suggest that fluid overload may be an even more prevalent and serious problem in PD patients compared to post-HD patients. Once again, our results show that fluid overload is closely associated with increased blood pressure and LVM index. OH/ECW, a derived parameter of fluid load measured by BIA, was a significant and independent determinant of SBP and LVMI.

Conflict of interest

The authors declare no conflicts of interest.

REFERENCES

[1] London GM, Marchais SJ, Metivier F, Guerin AP. Cardiovascular risk in end-stage renal disease: vascular aspects. Nephrol Dial Transplant 2000;15(Suppl. 5):97–104.

[2] Koc M, Toprak A, Tezcan H, Bihorac A, Akoglu E, Ozener IC. Uncontrolled hypertension due to volume overload contributes to higher left ventricular mass index in CAPD patients. Nephrol Dial Transplant 2002;17(9):1661–6.

[3] Wizemann V, Wabel P, Chamney P, Zaluska W, Moissl U, Rode C, et al. The mortality risk of overhydration in haemodialysis patients. Nephrol Dial Transplant 2009;24 (5):1574–9.

[4] Paniagua R, Ventura MD, Avila-Díaz M, Hinojosa-Heredia H, Méndez-Durán A, Cueto-Manzano A, et al. NT-proBNP, fluid volume overload and dialysis modality are independent predictors of mortality in ESRD patients. Nephrol Dial Transplant 2010;25(2):551–7.

[5] Wabel P, Chamney P, Moissl U, Jirka T. Importance of whole-body bioimpedance spectroscopy for the management of fluid balance. Blood Purif 2009;27(1):75–80.

[6] Moissl UM, Wabel P, Chamney PW, Bosaeus I, Levin NW, Bosy-Westphal A, et al. Body fluid volume determination via body composition spectroscopy in health and disease. Physiol Meas 2006;27(9):921–33.

[7] Crepaldi C, Soni S, Chionh CY, Wabel P, Cruz DN, Ronco C. Application of body composition monitoring to peritoneal dialysis patients. Contrib Nephrol 2009;163:1–6.

[8] Wizemann V, Rode C, Wabel P. Whole-body spectroscopy (BCM) in the assessment of normovolemia in hemodialysis patients. Contrib Nephrol 2008;161:115–8.

[9] Xu Y, Chen Y, Li D, Li J, Liu X, Cui C, et al. Hypertension, fluid overload and micro inflammation are associated with left ventricular hypertrophy in maintenance hemodialysis patients. Ren Fail 2013;35(9):1204–9.

[10] Gardin JM, Adams DB, Douglas PS, Feigenbaum H, Forst DH, Fraser AG, et al., American Society of Echocardiography. Recommendations for a standardized report for adult transthoracic echocardiography: a report from the American Society of Echocardiography's Nomenclature and Standards Committee and Task Force for a Standardized Echocardiography Report. J Am Soc Echocardiogr 2002;15(3): 275–90.

[11] Devereux RB, Reichek N. Echocardiographic determination of left ventricular mass in man. Anatomic validation of the method. Circulation 1977;55(4):613–8.

[12] Devolder I, Verleysen A, Vijt D, Vanholder R, Van Biesen W. Body composition, hydration, and related parameters in hemodialysis versus peritoneal dialysis patients. Perit Dial Int 2010;30(2):208–14.

[13] Fagugli RM, Pasini P, Quintaliani G, Pasticci F, Ciao G, Cicconi B, et al. Association between extracellular water, left ventricular mass and hypertension in haemodialysis patients. Nephrol Dial Transplant 2003;18(11):2332–8.

[14] Enia G, Mallamaci F, Benedetto FA, Panuccio V, Parlongo S, Cutrupi S, et al. Long-term CAPD patients are volume expanded and display more severe left ventricular hypertrophy than haemodialysis patients. Nephrol Dial Transplant 2001;16(7):1459–64.

[15] Konings CJ, Kooman JP, Schonck M, Dammers R, Cheriex E, Palmans Meulemans AP, et al. Fluid status, blood pressure, and cardiovascular abnormalities in patients on peritoneal dialysis. Perit Dial Int 2002;22(4):477–87.

[16] Antlanger M, Hecking M, Haidinger M, Werzowa J, Kovarik JJ, Paul G, et al. Fluid overload in hemodialysis patients: a cross-sectional study to determine its association with cardiac biomarkers and nutritional status. BMC Nephrol 2013;14:266.

[17] Demirci MS, Demirci C, Ozdogan O, Kircelli F, Akcicek F, Basci A, et al. Relations between malnutrition-inflammation-atherosclerosis and volume status. The usefulness of bioimpedance analysis in peritoneal dialysis patients. Nephrol Dial Transplant 2011;26(5):1708–16.

[18] Lang SM, Bergner A, Töpfer M, Schiffl H. Preservation of residual renal function in dialysis patients: effects of dialysis-technique-related factors. Perit Dial Int 2001;21(1):52–7.

[19] Tan BK, Chan C, Davies SJ. Achieving euvolemia in peritoneal dialysis patients: a surprisingly difficult proposition. Semin Dial 2010;23(5):456–61.

[20] Luo YJ, Lu XH, Woods F, Wang T. Volume control in peritoneal dialysis patients guided by bioimpedance spectroscopy assessment. Blood Purif 2011;31(4):296–302.

[21] Van Biesen W, Williams JD, Covic AC, Fan S, Claes K, Lichodziejewska-Niemierko M, et al., EuroBCM Study Group. Fluid status in peritoneal dialysis patients: the European Body Composition Monitoring (EuroBCM) study cohort. PLoS ONE 2011;6(2):e17148.

[22] Foley RN, Parfrey PS, Harnett JD, Kent GM, Murray DC, Barre PE. Impact of hypertension on cardiomyopathy, morbidity and mortality in end-stage renal disease. Kidney Int 1996;49 (5):1379–85.

[23] D'Amico M, Locatelli F. Hypertension in dialysis: pathophysiology and treatment. J Nephrol 2002;15(4):438–45.

[24] Alvarez-Lara MA, Martín-Malo A, Espinosa M, Rodríguez-Benot A, Aljama P. Blood pressure and body water distribution in chronic renal failure. Nephrol Dial Transplant 2001;16(Suppl. 1):94–7.

[25] Celik G, Kara I, Yilmaz M, Apiliogullari S. The relationship between bioimpedance analysis, haemodynamic parameters of haemodialysis, biochemical parameters and dry weight. J Int Med Res 2011;39(6):2421–8.
[26] Chen YC, Lin CJ, Wu CJ, Chen HH, Yeh JC. Comparison of extracellular volume and blood pressure in hemodialysis and peritoneal dialysis patients. Nephron Clin Pract 2009;113(2):c112–6.
[27] Yao YH, Fu CH, Ho SJ, Tsai SH, Ng YY, Chuang CL, et al. Peritoneal dialysis as compared with hemodialysis is associated with higher overhydration but non-inferior blood pressure control and heart function. Blood Purif 2012;34(1):40–7.
[28] Levin A, Singer J, Thompson CR, Ross H, Lewis M. Prevalent left ventricular hypertrophy in the predialysis population: identifying opportunities for intervention. Am J Kidney Dis 1996;27(3):347–54.
[29] Foley RN, Parfrey PS, Harnett JD, Kent GM, Martin CJ, Murray DC, et al. Clinical and echocardiographic disease in patients starting end-stage renal disease therapy. Kidney Int 1995;47(1):186–92.
[30] Chan CT, Greene T, Chertow GM, Kliger AS, Stokes JB, Beck GJ, et al., Frequent Hemodialysis Network (FHN) Trial Group. Determinants of left ventricular mass in patients on hemodialysis: Frequent Hemodialysis Network (FHN) Trials. Circ Cardiovasc Imaging 2012;5(2):251–61.