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Clinical significance of normohydration state in peritoneal dialysis patients

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ABSTRACT

Introduction: Assessing the fluid status of dialysis patients is crucial, as overhydration can lead to hypertension and left ventricular hypertrophy.
Objectives: We aimed to determine the hydration of peritoneal dialysis (PD) patients by using a bioimpedance device and performing concomitant echocardiographic measurements.
Patients and Methods: In our cohort, we enrolled PD patients in the study group and kidney transplantation waitlisted patients on hemodialysis (HD) or with stage 4-5 chronic kidney disease (CKD) in the control group. Fluid status was measured with a Fresenius Body Composition Monitor (BCM), and we performed an echocardiography examination. For statistical analysis, we used the Fisher's exact test for categorical variables and the Kruskal-Wallis test for continuous variables to compare groups.
Results: The patients' average age was 47 (SD 9.45), with a mild female predominance (54.3%). Overhydration was only found in 8 (12%) patients and was related to non-significantly lower ejection fraction (EF). Follow-up found that preserved EF was a non-significantly better outcome (HR: 0.881, 95% CI interval: 0.776; 1.001, $P=0.0514$). PD patients had significantly lower potassium levels ($P=0.0006$) and more angiotensin-converting-enzyme inhibitors (ACEis) (46%) and mineralocorticoid receptor antagonists (MRAs) (26%).
Conclusion: Lower potassium levels in continuous ambulatory peritoneal dialysis (CAPD) patients allow for the administration of drugs to treat cardiac remodeling and volume overload, which can help reduce patient mortality. The possible usage of MRAs in CKD could reduce cardiovascular mortality effectively.

Implication for health policy/practice/research/medical education:
Assessing the fluid status of dialysis patients is vital, as overhydration can lead to complications such as hypertension and left ventricular hypertrophy. Our study aimed to determine the hydration levels of peritoneal dialysis (PD) patients using a bioimpedance device and echocardiographic measurements. The study group comprised PD patients, while the control group included patients on the kidney transplant waitlist undergoing hemodialysis (HD) or those with stage 4-5 chronic kidney disease (CKD). Elevated potassium levels are uncommon in patients on the kidney transplant waiting list or receiving PD, providing valuable information for managing overhydration and potentially prescribing mineralocorticoid receptor antagonists (MRAs) to reduce cardiovascular mortality in this vulnerable population.
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Original

Introduction

The prevalence of left ventricular hypertrophy is 40% in chronic kidney disease (CKD), escalating to a staggering 75% in those with end-stage renal disease (ESRD). Hypertension and hypervolemia often increase heart muscle mass, especially in ESRD requiring renal replacement therapy (1). According to the classical hypothesis, hypertension primarily induces concentric hypertrophy, while hypervolemia and anemia induce eccentric hypertrophy (2-4). The co-occurrence of

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mechanical, neurohormonal, and metabolic factors in patients of mixed types contributes significantly to the development and maintenance of hypertrophy. Although these factors act simultaneously, their cumulative effect leads to maladaptive hypertrophy over time. Recent research has uncovered the crucial role of neurohormonal and other metabolic factors, alongside mechanical factors, in the development of hypertrophy. This new perspective underscores the importance of considering non-mechanical factors when evaluating the pathology of hypertrophy. In addition to activating the renin-angiotensin-aldosterone system, a significant role is attributed to secondary hyperparathyroidism, which is only one of the manifestations of calcium homeostasis disorder. Both reduced vitamin D levels and elevated parathyroid hormones cause an increase in the levels of phosphate and calcium phosphate present in circulation, which, in addition to their known skeletal effects, are also associated with vascular and valvular calcification and the development of left ventricular hypertrophy (2). Chronic kidney disease -mineral and bone disorder (CKD-MBD) has emerged as a key player in cardiovascular disease (CVD) pathogenesis. The clinical presentation of chronic kidney disease-mineral bone disorder (CKD-MBD) is typically characterized by hypocalcemia and hyperphosphatemia (5). In the context of CKD, a range of pathological processes have been recognized as significant contributors to the development of adverse cardiovascular complications. Fibroblast growth factor 23 (FGF-23) has recently become the focus of interest. Serum levels of FGF-23 increase in parallel with an increase in phosphate concentration and a decrease in the glomerular filtration rate (GFR). Its primary physiological role is to enhance urinary phosphate excretion and inhibit phosphate absorption from the intestinal tract (6). Even though the effects of the former are adaptive and beneficial in shaping the metabolism of chronic kidney patients, a significant side effect has also been revealed: FGF-23 is a potent inducer of left ventricular hypertrophy (4). Several studies support the association of FGF-23 with hard endpoints (major cardiovascular events, myocardial infarction, stroke, cardiovascular mortality) (7). When Klotho is absent in specific tissues, a soluble variant can be a transportable co-receptor for FGF23. As PD advances, FGF23 levels increase in the bloodstream; simultaneously, klotho expression in the kidneys decreases, resulting in klotho-independent impacts of FGF23 on the heart. These impacts can lead to atrial fibrillation, left ventricular hypertrophy, heart failure (HF) and mortality. Recently, studies have revealed that soluble klotho may mitigate some of these effects through various potential mechanisms (8). Left ventricular hypertrophy in patients with PD is a confirmed and significant prognostic factor for cardiovascular morbidity and mortality (9). Cardiovascular morbidity and mortality remain high in individuals on peritoneal dialysis (PD). An earlier analysis based on the United States Renal Data System indicated that dialysis cases whose condition was complicated by an acute myocardial infarction had high mortality from cardiac causes and poor long-term survival. Heart failure remains a significant challenge for patients and healthcare systems worldwide, including those on kidney replacement therapies. The presence of HF is a powerful predictor of adverse clinical outcomes in dialysis patients (10). Data from the United States Renal Data System suggest that HF is a widespread cause of hospitalization in dialysis patients, and the death rate after HF was 83% at three years (11).

Assessing fluid status in dialysis individuals is crucial. Managing persistent volume overload and instability during dialysis is a noteworthy challenge, which can result in symptomatic and asymptomatic intradialytic hypotension (IDH). This can lead to dialysis-induced myocardial ischemia (cardiac stunning) and long patient recovery times (10,12-14). Volume overload is present in 50% of hemodialysis (HD) individuals and in a similar percentage in the peritoneal dialysis population (11,15), complicating cardiac reserve and patient tolerance to treatment. At the other end of the spectrum, symptomatic hypotension complicates up to 17% of all dialysis sessions, while asymptomatic IDH has been reported to complicate nearly 26% of dialysis sessions (16). In routine clinical practice, a thorough assessment of fluid status is essential.

Objectives

We aimed to estimate our peritoneal dialysis population's hydration status with the help of BCM devices and analyze their echocardiographic results to eventually find a way to improve our pharmacological and dialysis prescription (17-21). Furthermore, another study's aim was to assess bioimpedance analysis and echocardiographic parameters, volume overload, and pulmonary hypertension in our PD patients and assess the need for subsequent management revision. We investigated whether there is a correlation between routine echocardiographic parameters and the results of BCM measurements. We compared PD patients' laboratory parameters with those of HD patients on the kidney transplant waiting list.

Patients and Methods

Study population

This was a cross-sectional, observational study. We enrolled patients with ESRD undergoing PD in the study group, and kidney transplantation waitlisted patients on HD or with stage 4-5 CKD in the control group. Informed consent was obtained from all patients and/or their legal guardian(s). We excluded some patients who needed HD treatment from our study. This was because we hypothesized that patients on the kidney transplant waiting list share similar characteristics with PD patients, such as better compliance and cardiac status. PD patients received therapy at the PD unit and the dialysis unit of the

department of nephrology at the university of Debrecen.

All patients underwent a comprehensive clinical and laboratory evaluation. Blood pressure, heart rate, demographic information, medical history, laboratory results, and medication use were recorded during monthly visits. Routine serum biochemical variables were analyzed, including glucose, serum creatinine, calcium, phosphorus, albumin, complete blood count, high-sensitive C-reactive protein, and a lipid profile level. The laboratory tests were carried out in the local laboratory. In addition to echocardiography, we also recorded a 12-lead electrocardiogram (ECG). A BCM measurement was performed to determine the dry weight. The BCM – Body Composition Monitor (Fresenius), a whole-body bioimpedance spectroscopy device (50 frequencies; 5–1000 kHz), was used in various clinical settings (17). The BCM was obtained before each HD session, and the data were transferred to the Fluid Management Tool (FMT) for further analysis. Overhydration was defined as more than 2 liters of fluid retention as measured by BCM. Exclusion criteria included any clinical condition predisposing the patient to pulmonary hypertension (e.g., chronic thromboembolic disease, interstitial lung diseases, connective tissue disorders, chronic obstructive pulmonary disease, congenital left-to-right shunt, primary pulmonary hypertension). Ejection fraction (EF) categories were classified as heart failure with reduced ejection fraction (HfrEF): left ventricular (LV) EF ≤40%; HF with mildly reduced EF (HFmrEF): LVEF 41%–49%; heart failure with preserved EF (HfpEF): LVEF50% (22).

Total clearance of waste products, endogen renal function, and dialysis was expressed as total Kt/V (urea) per week in HD and PD patients, while V was calculated according to Watson et al (23). Dialysis Kt/V (urea) per week was expressed in HD and in PD individuals as a measure of dialysis adequacy without residual kidney function. We based the study's statistical evaluation on the delivered dialysis dose due to a significant deviation in residual renal function. Anuria was defined as urine volume ≤100 mL/d.

Statistical analysis

As per statistics, comparisons between the two groups were made by student's *t* test, Mann-Whitney U test, or Wilcoxon test. Correlation between data was conducted by Pearson's or Spearman's correlation, and Fisher's exact and chi-squared tests assessed categorical variables. A 2-tailed *P* value of <0.05 was considered significant. Additionally, categorical variables were summarized as percentages and compared with a chi-square test.

Results

In our cohort, we enrolled 32 patients in the ESRD group and 34 patients in the control group (kidney transplantation waitlisted patients on HD or with stage 4-5 CKD). The mean age was 47 years old (SD: 9.45 *t* test; $P=0.1154$). As regards gender distribution, 54.3% of our patients were female, while in the control group slight male predominance was visible (with male patients accounting for 59.38% of the group). Relatively few patients were anuric (8.6 %), and most of the patients (91.4%) had residual urine (more than 1 liter). We found no significant differences between the groups in dialysis efficiency, body weight, hemoglobin, albumin, CRP, parathormone results, and hypertension medication. The only significant difference was the lower potassium value observed in PD-treated patients ($P=0.0006$). Table 1 summarizes the differences between chronic ambulatory peritoneal dialysis patients and the control group including those with advanced CKD receiving maintenance dialysis.

Table 2 shows the statistical results regarding the measured cardiac parameters among PD-treated and control groups patients.

We also analyzed mortality rates among the continuous ambulatory peritoneal dialysis (CAPD) and control groups, and adjusted them for age, body mass index, and EF. However, there were no significant differences between the two groups; Table 2 clearly shows that preserved EF is associated with slightly better outcomes (HR: 0.881, 95% CI interval: 0.776; 1.001, $P=0.0514$). Figure 1 illustrates well the significant differences in serum potassium levels between the two groups ($P=0.0006$).

Based on the patients' echocardiographic examinations, the following EF categories could be set up: 4 % of our patients had left ventricular (LV) EF ≤40% HF with diminished EF (HFrEF); 14 % of our patients had HF with mildly reduced EF (HFmrEF): LVEF 41–49%; and 84 % of our patients had HFpEF: LV EF 50%; ($P=0.282$ for across-group comparison). Based on BCM measurements, we found a non-significant correlation between hyperhydration and heart muscle wall thickness (Figure 2), but hypervolemia undoubtedly leads to heart muscle wall thickness.

We only found overhydration (more than 2 L volume overload) in 8 cases (12% of the total patients) by BCM, which was followed by dialysis prescription adjustment (reduced salt and fluid intake restriction, increased diuretic dose, increased frequency of PD fluid exchanges, and non-glucose containing PD solution were introduced). Not surprisingly, however, hyperhydration correlates with lower EF (Figure 3) and elevated calculated right ventricle pressure in CAPD individuals, even though this was not significant ($P=0.065$).

There was no significant correlation between tricuspid annular plane systolic excursion (TAPSE) results and hydration status, as demonstrated in Figure 4.

In all patients with echocardiography, TAPSE values showed an average of 23.17 mm (±4.5). We analyzed patient survival with Kaplan-Meier analysis in both groups, although found no significant differences (Figure 5a and 5b) in patient survival.

Moreover, we analyzed the correlation between EF

Table 1. Summary of the differences between chronic ambulatory peritoneal dialysis patients and the control group, including those with advanced CKD and receiving maintenance dialysis

	CAPD	HD/KTX waitlisted predialysis patients	*P* value[a]
No. of patients	32	34	
Male, (n (%))	16 (47.06%)	19 (59.38%)	0.337
Body weight (kg, SD)	75.57 (17.09)	74.7 (17.78)	0.867
Residual diuresis (mL/24 h) IQR	0-2100	0-1200	0.51
PD regime	85 % 4x exchange/day		
kt/V	1.57 (1.2-2.85)	1.56 (1.4-1.8)	0.54
Laboratory			
Hemoglobin (g/L, SD)	113.21 (sd: 13.31)	114.375 (sd: 12.098)	0.7119
Ferritin (mg/L)	113	146	0.045
albumin (g/L)	39 (0.5)	39.75 (0.55)	0.0317
potassium (mmol/L)	4.47 (0.506)	4.978 (0.619)	0.0006
phosphorus (mmol/L)	1.02-2.69 (0.37)	1.1-3.4 (0.45)	0.364
CRP (mg/L)	0.5-85 (3.84)	0.5-64.94 (3.905)	0.478
PTH µmol/L	45 (0.5)	51 (0.45)	0.345
Antihypertensive medication			
AA	23%	0	0.032
ACEI/ARB	46%	23%	0.045
BB	80%	76%	0.562
CCB	59%	62%	0.461

Abbreviations: AA: Alpha blockers; ACEI: Angiotensin-converting-enzyme inhibitors; ARB: Angiotensin receptor blockers; BB: Beta-blockers; CAPD: Continuous ambulatory peritoneal dialysis; CCB: Calcium-channel blockers; CRP: C-reactive protein; HD: Hemodialysis; IQR: Interquartile range; KTX: Kidney transplant; PD: Peritoneal dialysis; SD: Standard deviation; PTH: Parathormone.
[a] Student *t* test or Mann-Whitney U-test.

Table 2. Statistical results of the measured cardiac parameters of the PD-treated and control groups

	Contrast	Hazard ratio	95% CI	*P* value	Number (n)
Patient group	CAPD versus control	5.399	0.863;33.766	0.0715	66
Age at the initiation of RRT	Age at initiation RRT +1 unit	1.045	0.974; 1.122	0.2202	56
Age at the initiation of CAPD	Age at initiation RRT +1 unit	1.059	0.961; 1.166	0.2460	34
BMI, kg/m^2	+1 unit	1.085	0.909; 1.295	0.3677	66
EF (≤50%)	+1 unit	0.881	0.776; 1.001	0.0514	66
EF (mildly decreased versus preserved)	Mildly decreased versus preserved	1.077	0.092;12.608	0.9531	60
EF severe decreased versus preserved)	Severe decreased versus preserved	7.275	0.578;91.589	0.1246	60

Abbreviations: BMI: Body mass index; CAPD: Continuous ambulatory peritoneal dialysis; EF: Ejection fraction; RRT: Renal replacement therapy.

and patient survival. The Kaplan-Meier curve shows cumulative survival probabilities. A steeper slope indicates a higher event rate (death rate) and therefore a worse survival prognosis. A flatter slope indicates a lower event rate and therefore a better survival prognosis. Patients with severe reduced EF had worse survival prognosis compared to patients with preserved EF, even though not a significant one ($P=0.362$).

Discussion

The assessment of fluid status in dialysis individuals is of paramount importance (24). Measuring BCM is now considered a standard procedure and it provides essential information about the fluid distribution in the body. Using this method, we measure total body water, extracellular water, intracellular water, and overhydration (OH) levels in liters. We also obtain the percentage (OH%) of excess fluid that is greater than the anticipated extracellular water. Historically, the validation of bioimpedance methods for measuring fluid distribution has been done using various isotopes (such as potassium, bromide, hydrogen), tagged albumin, and dual-energy X-ray absorptiometry scans (25,26). Due to the absence or reduction of residual renal function and the intermittent nature of the dialytic treatment, HD patients may experience marked differences ranging from fluid overload (FO) to fluid

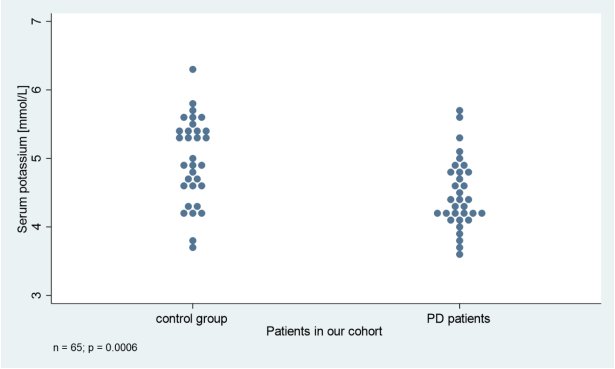


Figure 1. Potassium concentrations between the study groups.

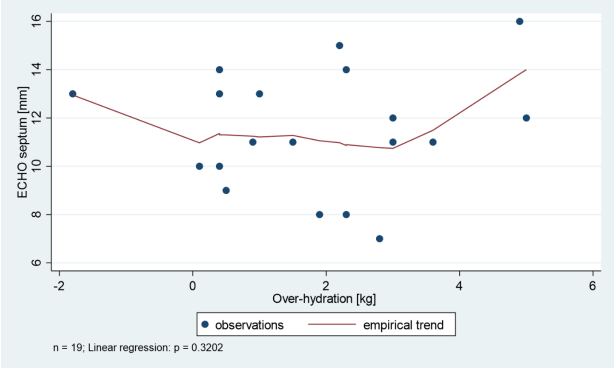


Figure 2. Overhydratation and echocardiographic findings.

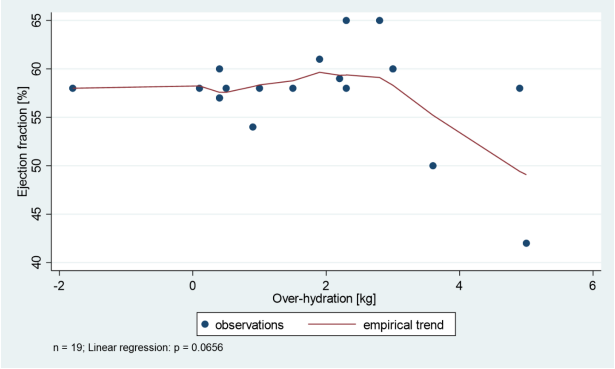


Figure 3. Ejection fraction and hydration status. Hyperhydration correlates with lower ejection fraction and elevated calculated right ventricle pressure in CAPD individuals, however this was not significant in our study. The blue dots represent patient observations, while the red line demonstrates empirical trends.

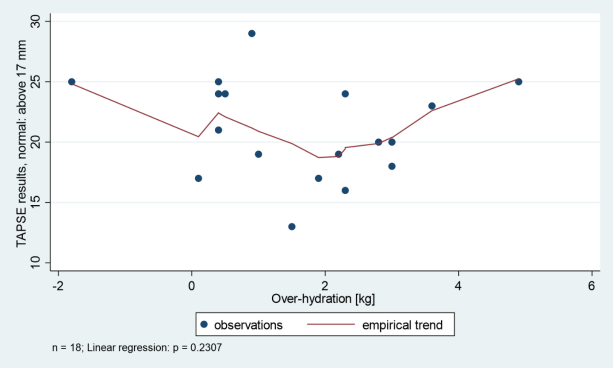
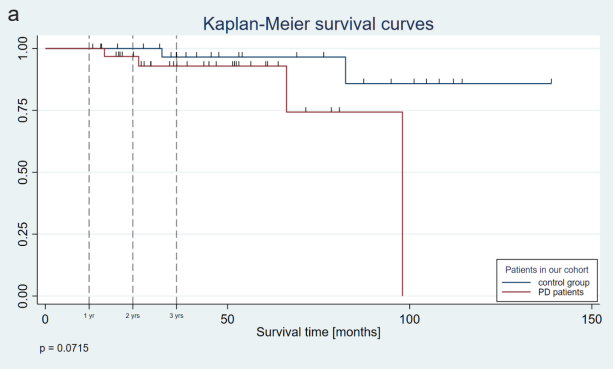


Figure 4. TAPSE (tricuspid annular plane systolic excursion) and hydration status. There was no significant correlation between hydration status and TAPSE results. The blue dots represent patient observations, while the red line demonstrates empirical trends.



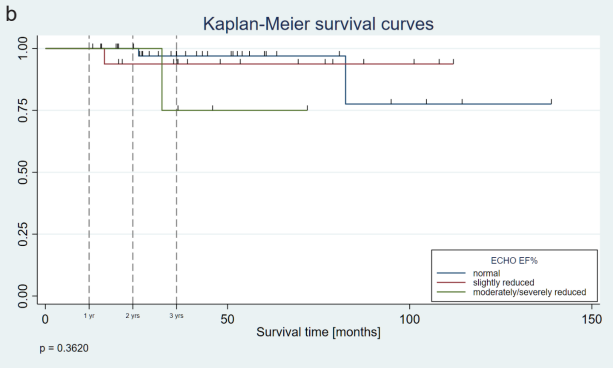


Figure 5. Kaplan-Meier survival curves. (a) Patients on PD had worst outcomes compared to control group. (b) Not surprisingly, patients with normal ejection fraction had the best outcomes compared to slightly, moderately, and severely reduced ejection fraction.

depletion (12,13). On the other hand, anuric peritoneal dialysis (PD) patients may be in a perpetual state of ongoing FO due to insufficient water and sodium removal from their dietary intake (10,14). Whereas FO may lead to hypertension and left ventricular hypertrophy (LVH), fluid depletion may result in IDH, tissue ischemia leading to cardiac stunning, loss of residual renal function (RRF), and potentially chronic impairment to the white matter in the brain (11,15,27). Patients with persistent FO face a significantly higher mortality risk compared to those with baseline FO of the same extent (28).

Many individuals with PD experience LVH, systolic and diastolic dysfunction, and cardiac valvular calcifications, which can increase the likelihood of mortality. Sudden cardiac death is the primary cause of death in this group, although there may also be other contributing factors (18-21). In this analysis, we compared the EF of HD+pre-dialysis individuals to that seen in PD cases. Due to the presence of a left-to-right shunt caused by

the arteriovenous (AV) fistula in HD patients, a chronic volume overload occurs independently of the total body water. This amplifies the volume overload in the HD group, leading to a lower EF for these patients, as evidenced in the analysis (18,19,24,29). In our findings, hyperhydration is often associated with weaker cardiac function and correlates with lower EF and elevated calculated right ventricle pressure in CAPD individuals. However, this is not statistically significant.

To summarize our results, we found that potassium was significantly increased in HD patients compared to CAPD patients, confirming previous findings in the literature (19). This result may be significant because it opens the door for additional drugs to be used in PD patients to treat cardiac remodeling and volume overload without less concern about potassium levels in PD patients (19,30-34). Angiotensin-converting-enzyme inhibitors (ACEis) and mineralocorticoid receptor antagonists (MRAs) can be used in CAPD individuals. We can reduce our patients' mortality and preserve longer residual kidney function in our patients, which can decrease the risk of pruritus as well (34,35). Lower potassium levels in PD patients means that ACEis could be prescribed for 46% of the patients and MRAs in the case of 26% of our CAPD patients. It is noteworthy that secondary hyperaldosteronism in CKD may pose several adverse cardiac effects. Therefore, in instances of normokalemia, the administration of MRAs may potentially reduce the risk of cardiovascular complications. This approach warrants consideration in the management of CKD patients with secondary hyperaldosteronism, particularly as a preventive measure against adverse cardiac outcomes (36).

Regarding kidney transplantation, patients with HF and preserved EF should be prioritized over those with reduced EF for better outcomes. However, achieving a normovolemic state can be more challenging for patients with higher potassium levels, as ACE inhibitors and MRAs may be limited. However, achieving a normovolemic state is more manageable in the HD group. Compared to PD patients, HD patients exhibited considerably higher calculated RV pressures. Our findings underscore the significance of frequent echocardiography in detecting this condition. It is crucial to prioritize improving blood pressure and volume control in addition to identifying practical treatment approaches that can prevent further deterioration in PD patients. Monitoring with BCM is one effective method to manage persistent overload in CAPD patients. Clinicians can modify the dialysis regime, restrict fluid intake, and use diuretics to preserve both LV and RV function and prevent deterioration of the peritoneal membrane. The most crucial benefit of this method is that it can improve the survival rate of patients. The study presented in this report is subject to several limitations. Foremost among these is the small sample size and the relatively brief follow-up period. As such, its findings are necessarily circumscribed and may not be generalizable to broader populations. A prospective investigation would be required to address these limitations and thoroughly test the hypothesis advanced in this study. Such an approach would enable a more comprehensive analysis of the issues under consideration and yield more robust conclusions.

Conclusion

Through thorough analysis, it has been determined that BCM is a valuable resource for clinicians seeking optimal volume control. This, in turn, contributes to preserving both left and right ventricular function, ultimately resulting in improved patient outcomes. Maintaining normovolemia in individuals undergoing PD treatment is paramount, as doing so can significantly enhance their cardiac well-being. Additionally, PD patients are often characterized by lower serum potassium levels, which can facilitate the optimal utilization of drug treatments. In this correlation, the usage of MRAs could benefit PD patients by lowering cardiovascular mortality.

Limitations of the study

It is important to note the limitations of our study. Firstly, we did not perform control heart ultrasound examinations during the follow-up, which could have yielded valuable results. It is likely that the cardiological changes associated with achieving normohydration contribute to improved survival, suggesting a need for further research in this area. Additionally, our study involved a relatively small number of cases and relied on data from only one center.

Authors' contribution

Conceptualization: Réka P. Szabó, Ákos G. Pethő.
Data curation: Amna Jousaf Hashmi, Boglárka Bujáki, Réka P. Szabó.
Formal analysis: László Kardos.
Investigation: Réka P. Szabó.
Methodology: Réka P. Szabó, Ákos G. Pethő.
Resources: István Varga.
Supervision: József Balla.
Validation: István Varga.
Visualization: László Kardos.
Writing–original draft: Réka P Szabó, Ákos G. Pethő.
Writing–review & editing: József Balla.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Ethical issues

All study-related procedures were performed in line with the 1964 Declaration of Helsinki's ethical standards and later amendments. All experimental protocols were approved by a named institutional and/or licensing committee (University of Debrecen Regional Research Ethics Committee-Rkeb/Institutional Research Ethics Committee-Ikeb). (Approval Number: DE RKEB/IKEB

5936-2021, 6178). Ethical issues (including plagiarism, data fabrication, double publication) have been completely observed by the authors.

Informed consent statement

Enrolled patients signed the informed consent form and agreed to participate in the study, and consented to the publication of the results in an online open-access journal. Our manuscript contains no identifying information or images of patients. Therefore, only aggregate data were used, and no identifiable patient data were revealed.

Data availability statement

The datasets generated and analyzed during the current study are not publicly available due to intellectual property but can be accessed through the corresponding author upon reasonable request.

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