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Research Article

Impact of Hemodialysis on Body Fluid Distribution and Phase Angle in Chronic Renal Failure: Insights from a Cross-Sectional Study

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Abstract

Aim: Bioelectrical impedance analysis (BIA) is a widely used, non-invasive technique that provides valuable information about phase angle (PhA) and hydration status, both of which are indicators of cellular health. In patients with chronic renal failure (CRF), fluid balance is often disrupted due to impaired kidney function. This study aimed to evaluate the effects of hemodialysis (HD) on segmental PhA values and body fluid distribution in patients with CRF.

Material and Methods: Patients receiving HD for CRF were enrolled. Using a multi-frequency (5, 50, 250 kHz) BIA device, segmental PhA and body fluid composition were measured.

Results: Post-dialysis measurements revealed a significant increase in phase angles across all examined segments. Concurrently, extracellular water (ECW), intracellular water (ICW) and total body water (TBW) volumes significantly decreased, whereas both ECW/TBW and ECW/ICW ratios increased.

Conclusion: HD leads to significant shifts in body fluid compartments, resulting in reduced hydration status and increased segmental phase angles values.

Keywords: Chronic renal failure, hemodialysis, phase angles, intracellular water

INTRODUCTION

Chronic Renal Failure (CRF) is a progressive and irreversible condition characterized by structural and functional deterioration of the renal parenchyma due to various etiological factors. In CRF, the ability to maintain basic physiological functions such as fluid-electrolyte balance, acid-base homeostasis, endocrine regulation, and the elimination of metabolic waste products is lost. The diagnosis of CRF is usually based on indicators of kidney damage, such as a persistent decrease in glomerular filtration rate (GFR) and the presence of proteinuria or albuminuria. These indicators reflect both functional impairment and glomerular damage and can see in individuals of all age groups. The global prevalence of CRF is increasing and constitutes a significant public health problem (1).

According to current clinical guidelines, CRF is defined by a GFR of less than 60 mL/min/1.73 m² for a duration of at least three months, and/or evidence of kidney damage such as a urinary albumin-to-creatinine ratio exceeding 30 mg/g, accompanied by structural or functional abnormalities identified through laboratory, imaging, or histopathological evaluation (2,3). As CRF progresses, the homeostatic regulation of body fluid compartments becomes increasingly disrupted. This disruption contributes to the accumulation of uremic toxins, disturbances in electrolyte and acid-base balance, and the emergence of a

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complex multisystem clinical syndrome involving cardiovascular, hematological, skeletal, and neuromuscular complications (4). Effective management of CRF requires comprehensive monitoring of renal function and fluid-electrolyte status to mitigate systemic effects and improve patient outcomes.

When the GFR declines below 15 mL/min/1.73 m², the condition is classified as end-stage renal failure (ESRF), necessitating the initiation of renal replacement therapies (RRT) such as HD, peritoneal dialysis, or renal transplantation (2-5). Among these modalities, HD remains the predominant treatment approach, accounting for approximately 80% of all RRTs globally. During HD, the patient's blood is circulated through a dialyzer where uremic toxins, metabolic waste products, and excess fluids are removed via diffusion and ultrafiltration (UF), thereby aiding in the restoration of fluid–electrolyte balance and the regulation of body fluid compartments (6-8).

In clinical nephrology, BIA has emerged as a non-invasive, rapid, and cost-effective method for assessing body composition and fluid status, particularly in patients with ESRF. Utilizing multi-frequency electrical currents and proprietary mathematical algorithms, BIA enables the quantification of total body water (TBW), extracellular water (ECW) and intracellular water (ICW) with a high degree of reproducibility and clinical utility. This capability is especially valuable for the detection and monitoring of volume overload, a common and life-threatening complication in dialysis patients (9-11).

Furthermore, phase angle (PhA), a parameter derived from the arctangent of reactance (Xc) to resistance (R) values obtained during BIA serves as a surrogate marker for cell membrane integrity, cellular mass, and overall nutritional and physiological status. In the context of HD, a higher PhA is associated with improved cellular function, lower inflammation, and better survival outcomes, while lower values have been linked to malnutrition, frailty, and increased mortality risk (12). Therefore, PhA has gained prominence as a clinically relevant biomarker not only for evaluating hydration and nutritional status but also for prognosticating morbidity and mortality in patients with various chronic illnesses, including ESRF (13,14).

The primary objective of this study is to evaluate the alterations in body fluid compartments and segmental PhA values before and after HD in patients with CRF.

MATERIAL AND METHODS

This study was conducted with a prospective design between May and June 2025 on patients undergoing HD treatment in the Department of Nephrology, Kırşehir Ahi Evran University Training and Research Hospital. A total of 41 patients were included in the study. During BIA, each participant was placed barefoot on the foot electrodes of the device in the correct anatomical position; after positioning their hands firmly grasping the arm electrodes of the device in a stable upright position and remaining motionless, measurements were performed within 15-20 seconds. Prior to dialysis, ICW, ECW, TBW and PhA values were obtained with a Tanita MC-780MA BIA analyzer (Tanita Corporation, Tokyo, Japan) with multi-frequency (5, 50, 250 kHz) measurement capacity. Fluid compartment values were calculated in kilograms by means of mathematical algorithms integrated into the instrument, and the ECW/TBW and ECW/ICW ratios were determined by the ratio of these numerical data to each other. PhA values were calculated separately over six different anatomical segments: Hand-Leg (H-L), Leg-Leg (L-L), Right Leg (RL), Left Leg (LL), Right Hand (RH) and Left Hand (LH). Height was measured with an accuracy of 0.1 cm using a BSM 370 (Biospace Co., Seoul, Korea) after the patients were positioned without shoes. When calculating body weight, a fixed clothing load of 1 kg was defined in the analyser, and body mass index (BMI) was calculated using the kg/m² formula. Following the initial BIA measurement, HD + UF treatment was administered for 3.5 to 4 hours, taking into account the average dry weight values determined individually for each participant. Approximately 20 minutes after dialysis, measurements were repeated using the same device and method. Within the scope of the obtained data, the pre- and post-dialysis values of the variables were compared.

Individuals with acute or chronic infection, history of malignancy, cardiac arrhythmia or pacemaker, or inability to tolerate HD and complete the procedure effectively were excluded.

Ethical approval was granted by the Ethics Committee of Kırşehir Ahi Evran University Faculty of Medicine (Ethics No: 2025-08/83), the study was conducted in accordance with the principles of the Declaration of Helsinki and informed written consent was obtained from all participants.

Statistical Analyses

Statistical analyses were performed using the SPSS software package (IBM SPSS Statistics for Windows, Version 29.0, Armonk, NY: IBM Corp., USA). In the descriptive statistics of the variables, normally distributed variables were given as arithmetic mean±standard deviation, median (Min-Max) and non-normally distributed variables were given as median (25th-75th percentile). Normality assumptions of continuous data were tested with Kolmogorov-Smirnov and Shapiro-Wilk tests. The assumption of homogeneity of variances was tested with Levene's homogeneity test. Depending on the fulfill-

ment of the assumptions; Paired t test, Wilcoxon signed rank test were used in the comparisons of BIA measurements of patients before and after dialysis, while the comparisons between female and male groups were analyzed with Independent t test, Mann-Whitney U test. In all statistics, $p<0.05$ was considered statistically significant.

RESULTS

A total of 41 patients were enrolled in this study, comprising 14 males (34.1%) and 27 females (65.9%). The mean age of the overall patient population was 55.17 ± 13.16 years. The results of the measurements obtained before and after HD are summarized in Table 1. Analysis of these results revealed a statistically significant reduction in both body weight (kg) and BMI following HD treatment.

PhA values, assessed across six distinct anatomical segments namely H-L, RL, LL, RH, LH and L-L demonstrated a statistically significant increase post-HD in all segments examined. These increases in PhA were found to be highly significant, indicating improved cellular membrane integrity and potential shifts in body composition attributable to the dialysis process.

Furthermore, fluid compartment analyses indicated that ICW, ECW and TBW volumes decreased significantly following HD. Conversely, both the ECW/TBW and ECW/ICW ratios increased significantly post-HD, suggesting a relative redistribution of body fluid compartments and an altered hydration status.

Descriptive statistical data regarding sex-based pre- and post-HD differences in measurements are provided in Table 2. Within this context, a statistically significant sex difference was observed in the reduction of ECW values, with female patients exhibiting a greater ECW loss compared to their male counterparts. No statistically significant sex differences were identified in the other measured parameters.

Table 1. Pre- and post-dialysis changes in patients' weight, BMI, multi-segmental phase angles, and fluid composition

Variables/n	Pre-Dialysis (n:41)	Post-Dialysis (n:41)	p
Weight	73.66±16.15 72.80(41.90-117.40)	70.55±16.06 70.20(38.90-113.80)	0.000[&]
BMI	27.64±5.69 25.90(16.80-43.10)	26.48±5.66 24.80(15.60-41.80)	0.000[&]
H-L PhA	4.42±0.79 4.30(2.80-6.70)	5.14±0.98 5.20(2.60-7.50)	0.000[&]
RL PhA	3.68±1.04 3.50(1.70-7.30)	4.50±1.23 4.60(1.90-6.50)	0.00[0&]
LL PhA	3.66±1.07 3.60(1.70-7.70)	4.59±1.33 4.50(1.60-8.50)	0.000[&]
RH PhA	5.24±0.81 5.10(3.60-7.10)	5.74±1.02 5.70(3.60-8.40)	0.00[0&]
LH PhA	5.11±0.93 5.10(3.60-8.60)	5.66±1.02 5.80(3.50-9.10)	0.000[&]
L-L PhA	3.71±0.91 3.70(1.90-6.00)	4.61±1.25 4.70(1.90-7.50)	0.000[&]
ICW (kg)	21,87±5,09 20.90(18.40-23.90)	19,55±4,81 18.60(16.70-22.20)	0.000[#]
ECW(kg)	17.056±3.07 16.90(10.50-24.20)	15.79±3.05 15.70(9.20-22.80)	0.000[&]
TBW (kg)	39,19±7,91 37.60(34.70-43.30)	35,62±7,59 33.90(31.60-38.90)	0.000[#]
ECW/TBW	0.43±0.02 0.43(0.36-0.48)	0.44±0.03 0.44(0.35-0.49)	0.000[&]
ECW/ICW	0.79±0.079 0.78(0.59-0.93)	0.82±0.09 0.81(0.60-0.99)	0.000[&]

&: Paired t test, #: Wilcoxon signed rank test
BMI:Body Mass Index, H-L;Hand-Leg, L-L;Leg-Leg , RL;Right Leg, LL;Left Leg, RH;Right Hand, LH; Left Hand, kg;kilogram,ICW;Intracellular Water, ECW;Extracellular water, TBW; Total body water

Table 2. Sex-based analysis of pre- and post-HD differences in variables

Pre-Post HD Differences in Variables	Total n=41	Male n=14	Female n=27	p
Weight (kg)	3.10±0.74 3.10(1.20-5.10)	3.30±0.81 3.40(1.20-4.50)	3.00±0.69 3.00(1.60-5.10)	0.235*
BMI	1.16±0.27 1.20(0.50-2.10)	1.13±0.24 1.20(0.24-1.20)	1.18±0.29 1.10(0.60-2.10)	0.624*
H-L PhA	0.72±0.45 0.70(-0.20-2.10)	0.69±0.58 0.70(-0.20-2.10)	0.74±0.37 0.70(0.00-1.60)	0.751*
RL PhA	0.81±0.55 0.80(-1.00-1.90)	0.78±0.43 0.85(0.10-1.40)	0.82±0.60 0.70(-1.00-1.90)	0.828*
LL PhA	0.93±0.74 0.90(-1.80-3.20)	1.00±0.80 0.90(-0.10-3.20)	0.89±0.73 0.80(-1.80-1.80)	0.680*
RH PhA	0.49±0.46 0.50(-0.40-2.10)	0.48±0.31 0.45(-0.20-1.10)	0.50±0.53 0.50(-0.40-2.10)	0.909*
LH PhA	0.55±0.52 0.50(-0.40-2.40)	0.40±0.44 0.40(-0.40-1.20)	0.65±0.55 0.50(-0.30-2.40)	0.300#
L-L PhA	0.90±0.49 0.90(0.00-2.20)	0.89±0.57 0.95(0.00-2.20)	0.90±0.46 0.80(0.10-1.70)	0.931*
ICW	2.31±0.85 2.50(0.50-4.60)	2.52±1.13 2.60(0.50-4.60)	2.21±0.65 2.10(1.10-3.50)	0.279*
ECW	1.26±0.34 1.30(0.20-1.80)	1.07±0.39 1.15(0.20-1.60)	1.35±0.28 1.30(0.90-1.80)	0.013*
TBW	2.65±1.43 2.66(-0.63-5.68)	2.13±1.83 2.31(-0.63-5.68)	2.92±1.13 2.85(0.84-5.25)	0.097*
ECW/TBW	0.00±0.00 0.00(-0.01-0.03)	0.01±0.00 0.00(0.00-0.03)	0.00±0.00 0.00(-0.01-0.02)	0.078
ECW/ICW	0.02±0.02 0.02(-0.03-0.10)	0.03±0.03 0.02(-0.00-0.10)	0.02±0.02 0.02(-0.03-0.06)	0.243*

*: Independent t test, #Mann-Whitney U
BMI: Body Mass Index, PhA:Phase Angle,H-L;Hand-Leg, L-L;Leg-Leg , RL;Right Leg, LL;Left Leg, RH;Right Hand, LH; Left Hand, kg;kilogram, ICW;Intracellular water , ECW;Extracellular water, TBW; Total body water

DISCUSSION

In this study, we investigated the effects of HD on multisegmental PhA values and fluid compartment distributions in patients with CRF. Using multifrequency BIA (measured at 5, 50, and 250 kHz), a statistically significant increase in PhA values was observed across all six anatomical segments assessed. These segments included both upper and lower extremities, as well as segmental combinations, reflecting a consistent improvement in tissue electrical properties following HD ($p < 0.001$).

In parallel, HD resulted in statistically significant reductions in all measured body fluid compartments, including ICW, ECW, and TBW ($p < 0.001$). Despite the overall fluid loss, post-dialysis assessments revealed significant increases in the ECW/TBW and ECW/ICW ratios ($p < 0.001$), suggesting a relative redistribution of body fluids. These findings indicate that HD not only facilitates the removal of excess fluid but also induces measurable changes in bioelectrical parameters that may reflect shifts in cellular health and membrane integrity (Figure 1).

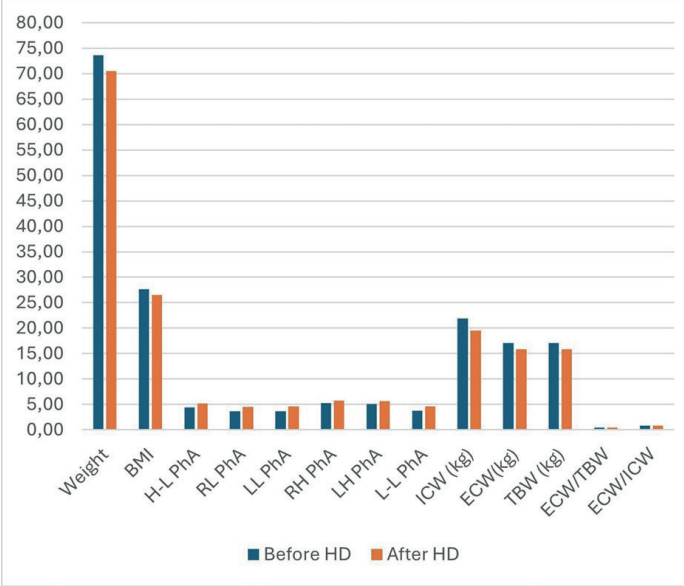

Fig.1 Differences in variables before and after HD

Recent evidence indicates a growing prevalence of fluid overload among patients undergoing HD for CRF. Notably, a considerable proportion of patients who are clinically assessed

as euvolemic or even dehydrated have been found to exhibit overhydration (OH) when objectively evaluated using BIA (15,16). In this regard, BIA has emerged as a valuable diagnostic modality, offering a non-invasive, cost-effective, and reproducible method for accurately assessing hydration status. Its efficacy has been demonstrated across a range of clinical contexts, particularly in the management of volume status in patients with heart failure and CRF (17,18).

BIA has been shown to be a biomarker that improves the clinical outcomes of HD by supporting more sensitive UF strategies and thus helping to regulate blood pressure (19).

In a study conducted by Kim et al., BIA-derived parameters were compared between pre- and post-dialysis states in both patient and control cohorts. The authors reported significant reductions in ICW, ECW, TBW and the ECW/TBW ratio following HD treatment, reflecting effective fluid removal (20). In contrast, the findings of our study revealed divergent trends: although reductions in absolute fluid compartments were observed, both ECW/TBW and ECW/ICW ratios increased post-dialysis. This paradoxical outcome is hypothesized to stem from suboptimal UF, potentially due to limitations in achieving the target dry weight or inadequate removal of interstitial fluid during HD sessions.

Additionally, Visser et al. explored the temporal effects of BIA measurement by comparing assessments conducted within 30 minutes and beyond 30 minutes pre- and post-HD. Their results demonstrated consistent declines in body weight, OH, TBW and ECW, accompanied by a statistically significant increase in PhA, an indicator of cellular integrity and nutritional status (21). These findings underscore the sensitivity of BIA in capturing dynamic changes in fluid compartments and cellular health, highlighting its utility not only in fluid management but also in the broader clinical evaluation of dialysis patients.

Collectively, the existing body of evidence supports the integration of BIA into routine clinical practice for the management of fluid status in HD patients. Further research is warranted to standardize measurement protocols and to explore its role in guiding individualized UF strategies.

Numerous scientific studies have highlighted the significance of PhA, derived from BIA, as a valuable biomarker in CRF-related research. Notably, Han et al. (22) demonstrated that lower PhA values were significantly associated with decreased GFR and indicators of malnutrition in patients with stage 5 CRF. Their findings suggest that diminished PhA may serve as a reliable biological indicator of both impaired renal function and poor nutritional status in this population. Given the role of PhA as a non-invasive, cost-effective parameter reflective of cellular health and integrity, its clinical utility in the assessment and monitoring of patients with advanced renal disease warrants further investigation and integration into routine nephrological practice.

Similarly, a growing body of evidence suggests that a reduced PhA is associated with the progression of CRF, particularly in patients with type 2 diabetic nephropathy (23). In a cross-sectional study conducted by Tan et al. (24) it was observed that patients with CRF undergoing HD exhibited significantly lower PhA values compared to healthy controls. The study underscored PhA as a strong predictive marker for malnutrition in this population.

Moreover, several studies have documented significant associations between PhA and fluid balance as well as physical function. Specifically, PhA has been found to correlate inversely with fluid overload and positively with physical performance. OH, often assessed through elevated ECW/ICW ratios, has been consistently linked to lower PhA values (25), while higher levels of physical performance are independently associated with elevated PhA (26).

Gonzalez et al. (27), in a study involving 1,442 healthy adults, reported that a high ECW/ICW ratio was more strongly associated with a low PhA than other commonly measured variables such as age or BMI. Similarly, Francisco et al. (28) found that among athletes, higher PhA values were significantly associated with increased ICW mass and a lower ECW/ICW ratio, independent of age, height, or sport type. These findings emphasize the role of PhA as a sensitive indicator of cellular hydration and integrity.

In the context of HD, the relationship between ICW and PhA has been effectively monitored through BIA. Studies consistently report that low ICW levels and elevated ECW/ICW ratios are significantly associated with lower PhA values in this patient group (29).

Furthermore, a meta-analysis conducted by Wang et al. (30) reinforced the prognostic value of PhA and fluid distribution metrics in dialysis patients. The analysis demonstrated that each 0.1 unit increase in the ECW/ICW ratio was associated with a heightened risk of mortality among CRF patients receiving peritoneal dialysis or HD. Conversely, each one-degree increase in PhA was found to be protective, correlating with reduced all-cause mortality and a lower incidence of cardiovascular events.

Although both ECW and ICW compartments decline during the course of HD, evidence suggests that the reduction in ECW is more pronounced, particularly during the early phases of the procedure (31). This disproportionate fluid removal, primarily achieved through UF, is accompanied by a dynamic redistribution of body fluids, which in turn influences bioelectrical imped-

ance parameters specifically R and Xc (21). These physiological alterations affect the accuracy and interpretation of body composition measurements derived from BIA. The observed post-dialysis increase in PhA is hypothesized to result from these shifts, reflecting improved cellular membrane integrity and relative restoration of intracellular volume following the reduction in extracellular fluid overload. Thus, the PhA elevation following HD may serve as an indirect indicator of fluid redistribution and improved cellular health status (Figure 2).

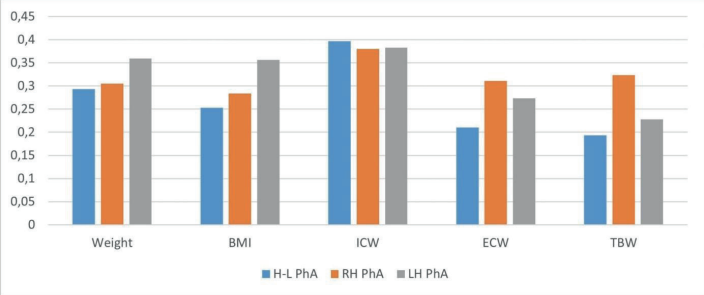

Fig.2 Relationship of H-L, RH, and LH segmental PhA with weight, BMI, ICW, ECW, and TBW

One of the primary strengths of the present study is the significant increase observed in PhA measurements across six distinct anatomical segments throughout the HD procedure. To the best of our knowledge, this represents the first study in the literature to evaluate PhA changes encompassing all six segments, thereby offering a novel and comprehensive contribution to the existing body of research.

Nonetheless, the study is not without limitations. Notably, the observed post-dialysis increase in the ECW/TBW and ECW/ICW ratios diverges from the trends typically reported in the literature and from established clinicopathologic expectations. This inconsistency may be attributable to suboptimal UF in certain patients, which may have limited the expected removal of extracellular fluid. Despite this, the finding further underscores the clinical utility and diagnostic sensitivity of BIA in the evaluation of fluid status among patients with CRF.

The integration of BIA-derived fluid compartment analysis, in conjunction with patients' known dry weights, allows for the determination of a euhydrated (eudolomic) body composition. This approach holds promise for identifying reliable biomarkers to guide clinical decision-making and provides a robust foundation for future prospective investigations aimed at optimizing fluid management and nutritional assessment in CRF populations.

HD treatment was found to exert significant and measurable effects on PhA and body fluid distribution across six anatomical segments, as assessed by multifrequency BIA. The findings of this study demonstrate that HD contributes to a marked increase in PhA values, reflecting improved cellular integrity, while simultaneously facilitating the regulation of fluid compartments. These changes collectively support the therapeutic role of HD in maintaining fluid homeostasis in patients with CRF.

The observed reductions in ICW, ECW and TBW following HD indicate effective fluid removal and rebalancing, which are critical components of volume management in CRF. Moreover, the post-dialysis elevation in PhA may serve as a surrogate marker for the restoration of cell membrane functionality and overall cellular health. In this context, PhA emerges as a potentially valuable biomarker for assessing the biological efficacy of HD beyond conventional clinical and biochemical parameters.

Taken together, these results underscore the utility of BIA not only for fluid status monitoring but also for providing insights into the physiological responses to HD. Future studies should explore the prognostic implications of PhA changes over time and validate its role in guiding individualized dialysis strategies.

This study presents several methodological limitations that should be acknowledged when interpreting the findings. First, the investigation was conducted at a single center and involved a relatively small patient cohort, which may limit the generalizability of the results to broader populations of patients undergoing HD. Additionally, several clinically relevant variables were not included in the analysis. These include the etiology of CRF, the presence and severity of comorbid conditions, pre- and post-dialysis GFR, Kt/V values (as a marker of dialysis adequacy), serum electrolyte and blood gas parameters, hemoglobin and hematocrit levels, as well as established indicators of inflammation, malnutrition, and body composition (e.g., fat mass and muscle mass). The exclusion of these parameters precluded a more comprehensive evaluation of their potential influence on PhA measurements.

Moreover, the study was restricted to acute-phase assessments, as it was based on data obtained from a single HD session. This cross-sectional design does not permit an evaluation of longitudinal changes in PhA or related physiological adaptations over time. As a result, the study is limited in its ability to capture chronic or cumulative effects of HD on body composition and hydration status.

In light of these limitations, future research should focus on multicenter studies involving larger and more diverse patient populations. Such studies should incorporate repeated HD sessions and employ longitudinal follow-up designs to better assess the long-term clinical implications of PhA dynamics. Inclusion of a broader range of biochemical, nutritional, and metabolic parameters would also enhance the understanding of the multifactorial determinants of PhA in patients with CRF.

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Data Availability: The data that support the findings of this study are available on request from the corresponding author.

Conflict of interest: The authors have no competing interests to declare that are relevant to the content of this article.

Ethical approval: Ethical approval was granted by the Ethics Committee of Kırşehir Ahi Evran University Faculty of Medicine (Ethics No: 2025-08/83), the study was conducted in accordance with the principles of the Declaration of Helsinki and informed written consent was obtained from all participants.

REFERENCES

1. Dai P, Chang W, Xin Z, et al. Retrospective study on the influencing factors and prediction of hospitalization expenses for chronic renal failure in China based on random forest and LASSO regression. Front Public Health. 2021;9:678276.
2. Hashmi MF, Benjamin O, Lappin SL. End-stage renal disease. 2018
3. Scott IA, Scuffham P, Gupta D, et al. Going digital: a narrative overview of the effects, quality and utility of mobile apps in chronic disease self-management. Aust Health Rev. 2018;44:62–82.
4. Zhang L, Wang F, Wang L, et al. Prevalence of chronic kidney disease in China: a cross-sectional survey. Lancet. 2012;379:815–22.
5. Sgambat K, Cheng YI, Charnaya O, Moudgil A. The prevalence and outcome of children with failure to thrive after pediatric kidney transplantation. Pediatr Transplant. 2019;23:e13321.
6. Chuasuwan A, Pooripussarakul S, Thakkinstian A, et al. Comparisons of quality of life between patients underwent peritoneal dialysis and hemodialysis: a systematic review and meta-analysis. Health Qual Life Outcomes. 2020;18:191.
7. Çalapkorur S, İradeli E. Hemodiyaliz hastalarında beslenme durumunun değerlendirilmesinde yeni bir yöntem: faz açısı. Cumhuriyet Univ Sağlık Bilim Enst Derg. 2023;8:58–64.
8. Vadakedath S, Kandi V. Dialysis: a review of the mechanisms underlying complications in the management of chronic renal failure. Cureus. 2017;9:e1603.
9. Ng JK-C, Lau SL-F, Chan GC-K, et al. Nutritional assessments by bioimpedance technique in dialysis patients. Nutrients. 2023;16:15.
10. Zoccali C, Moissl U, Chazot C, et al. Chronic fluid overload and mortality in ESRD. J Am Soc Nephrol. 2017;28:2491–7.
11. Van Biesen W, Verger C, Heaf J, et al. Evolution over time of volume status and PD-related practice patterns in an incident peritoneal dialysis cohort. Clin J Am Soc Nephrol. 2019;14:882–93.
12. Kyle UG, Bosaeus I, De Lorenzo AD, et al. Bioelectrical impedance analysis—part II: utilization in clinical practice. Clin Nutr. 2004;23:1430–53.
13. Norman K, Wirth R, Neubauer M, et al. The bioimpedance phase angle predicts low muscle strength, impaired quality of life, and increased mortality in old patients with cancer. J Am Med Dir Assoc. 2015;16:173. e117–22.
14. Zeng Y, Xu Y, Zhang B, et al. Clinical prognostic role of bioimpedance phase angle in diabetic and non-diabetic hemodialysis patients. Asia Pac J Clin Nutr. 2022;31:619–25.
15. Kwan BC-H, Szeto C-C, Chow K-M, et al. Bioimpedance spectroscopy for the detection of fluid overload in Chinese peritoneal dialysis patients. Perit Dial Int. 2014;34:409–16.
16. Ronco C, Verger C, Crepaldi C, et al. Baseline hydration status in incident peritoneal dialysis patients: the initiative of patient outcomes in dialysis (IPOD-PD study). Nephrol Dial Transplant. 2015;30:849–58.
17. La Porta E, Faragli A, Herrmann A, et al. Bioimpedance analysis in CKD and HF patients: A critical review of benefits, limitations, and future directions. J Clin Med. 2024;13:6502.
18. Kyle UG, Bosaeus I, De Lorenzo AD, et al. Bioelectrical impedance analysis part I: review of principles and methods. Clin Nutr. 2004;23:1226–43.
19. Scotland G, Cruickshank M, Jacobsen E, et al. Multiple-frequency bioimpedance devices for fluid management in people with chronic kidney disease receiving dialysis: a systematic review and economic evaluation. Health Technol Assess. 2018;22:1-138.
20. Kim H, Choi GH, Shim KE, et al. Changes in bioimpedance analysis components before and after hemodialysis. Kidney Res Clin Pract. 2018;37:393-403.

21. Visser WJ, van Ruijven IM, Severs D. Measuring body composition in hemodialysis patients: before or after hemodialysis? Clin Nutr Open Sci. 2023;51:62–6.
22. Han B-G, Lee JY, Kim J-S, Yang J-W. Decreased bioimpedance phase angle in patients with diabetic chronic kidney disease stage 5. Nutrients. 2019;11:2874.
23. Low S, Pek SLT, Moh AMC, et al. Association between lower phase angle and chronic kidney disease progression in type 2 diabetes patients. Ann Acad Med Singap. 2023;52:125-34.
24. Tan R-s, Liang D-h, Liu Y, et al. Bioelectrical impedance analysis–derived phase angle predicts protein–energy wasting in maintenance hemodialysis patients. J Ren Nutr. 2019;29:295–301.
25. Wang K, Zelnick LR, Chertow GM, et al. Body composition changes following dialysis initiation and cardiovascular and mortality outcomes in CRIC (chronic renal insufficiency cohort): A bioimpedance analysis substudy. Kidney Med. 2021;3:327–34. e321.
26. Li X, Zhang K, Guo Q, et al. Impedance-derived phase angle as an indicator of physical function in maintenance hemodialysis patients. Nutrition. 2025;136:112795.
27. Gonzalez MC, Barbosa-Silva TG, Bielemann RM, et al. Phase angle and its determinants in healthy subjects: influence of body composition. Am J Clin Nutr. 2016;103:712-6.
28. Francisco R, Matias CN, Santos DA, et al. The predictive role of raw bioelectrical impedance parameters in water compartments and fluid distribution assessed by dilution techniques in athletes. Int J Environ Res Public Health. 2020;17:759.
29. Guo Y, Zhang M, Ye T, et al. Application of bioelectrical impedance analysis in nutritional management of patients with chronic kidney disease. Nutrients. 2023;15:3941.
30. Wang Y, Gu Z. Effect of bioimpedance-defined overhydration parameters on mortality and cardiovascular events in patients undergoing dialysis: a systematic review and meta-analysis. J Int Med Res. 2021;49:3000605211031063.
31. Yu S-J, Kim D-h, Oh D-J, et al. Assessment of fluid shifts of body compartments using both bioimpedance analysis and blood volume monitoring. J Korean Med Sci. 2006;21:75-80.