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Point-of-care ultrasonography (POCUS) versus clinical standard care in assessing the volume status in maintenance hemodialysis patients while using bioimpedance analysis (BIA) as a reference

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ABSTRACT

Introduction: Volume overload contributes to cardiovascular and all-cause mortality in hemodialysis patients.

Objectives: To assess agreement between point-of-care ultrasonography (POCUS) and standard clinical assessment for evaluating volume status in maintenance hemodialysis patients, using bioimpedance analysis (BIA) as a reference.

Patients and Methods: This cross-sectional study included 45 end-stage renal disease (ESRD) patients on maintenance hemodialysis. Patients with decompensated liver disease, ascites, heart failure, active infection, or pregnancy were excluded. Volume status was assessed before and after mid-week dialysis using blinded clinical evaluation and POCUS, including lung ultrasound (B-lines), inferior vena cava (IVC) diameter, IVC collapsibility index, and focused echocardiography (FOCUS). Furthermore, POCUS was conducted by a blinded operator, since BIA served as the reference standard.

Results: In linear regression analyses, post-dialysis reductions in right ventricular (RV) longitudinal dimension, left ventricular end-diastolic dimension (LVEDD), and B-lines predicted BIA-estimated excess weight in the POCUS model (all $P<0.05$), whereas post-dialysis reductions in RV longitudinal dimension, left ventricular end-systolic dimension (LVESD) and the clinical estimated weight predicted it in the combined clinical and POCUS model (all $P<0.05$). The combined use of clinical assessment and POCUS demonstrated the strongest agreement with BIA (ICC = 0.826, $P<0.001$) and the highest accuracy, with 64.4% of the patients showing weight difference of ≤0.5 kg compared with BIA estimates.

Conclusion: Integrating clinical assessment with POCUS improves the accuracy and reliability of volume status evaluation in hemodialysis patients compared with either method alone. Our limitations in this study were the single-center design, small sample size, and operator dependence of POCUS measurements.

Implication for health policy/practice/research/medical education:
Combining point-of-care ultrasonography (POCUS) with clinical assessment offers more accurate fluid management and improved volume status assessment in hemodialysis patients.

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Introduction

Accurate determination of the patient's volume status, using reliable methods for assessing fluid overload, is one of the primary goals of end-stage renal disease (ESRD) patients' management (1). There is a lack of standardized methods for dry weight adjustment and no global method for volume assessment in hemodialysis patients (2).

The 'dry weight' probing approach has been used by nephrologists to maintain a salt and water homeostasis in hemodialysis patients (3). By obtaining a thorough history and examining for physical signs like jugular venous pressure, rales, peripheral edema, and third heart sounds,

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fluid status could be assessed. These signs are useful in severe cases, but are not sensitive enough to identify mild volume overload (4). Volume overload predisposes patients to pulmonary edema, exacerbates pre-existing hypertension and increases mortality, heart failure, left ventricular (LV) hypertrophy, and arterial stiffness (5).

Even though clinical 'dry weight' approach treatment strategy has been linked to improved cardiovascular outcomes, it was challenged by recent research, demonstrating that vigorous fluid removal during intermittent dialysis is linked to cardiovascular stress and possible organ damage. Thus, a more accurate approach is necessary (3).

Point-of-care ultrasonography (POCUS) has been suggested as the fifth pillar of physical examination in light of the miniaturization of ultrasound devices (6). This approach helps clinicians make quick decisions using objective data (7). With basic training, POCUS skills, including assessment of the lung, inferior vena cava (IVC), and focused cardiac ultrasound (FOCUS) can be rapidly learned (8).

Lung ultrasound (LUS) is a well-established method for quantifying extravascular lung water. The important metric for estimating lung water is counting the ultrasound B-lines. B-lines, which are likely to occur before the patient becomes dyspneic, serve as an early indicator of extravascular lung water (9).

The IVC is used to assess volume status by indirectly reflecting central venous pressure and fluid responsiveness, as it carries two-thirds of systemic venous return. Although IVC ultrasound is easy to perform, interpreting the results is more complex, and several barriers limit its wider clinical use. Besides the circulating volume, IVC diameter changes during respiration can also be influenced by the right ventricular (RV) function and the intrathoracic and intra-abdominal pressure gradient (10).

Normal right atrial pressure (RAP) of 3 mm Hg (0–5 mm Hg) is suggested by an IVC ≤2.1 cm with >50% collapse; high RAP of 15 mm Hg (10–20 mm Hg) by an IVC >2.1 cm with <50% collapse; and intermediate values (5–10 mm Hg) by findings in between (11).

Focused echocardiography (FOCUS) is a limited study intended to assess particular issues, such as the presence of pericardial effusions and the left and RV function. The diameter of the RV is normally less than two thirds that of the left ventricle (LV). In the parasternal short axis view, volume overload causes the RV to dilate and the interventricular septum to flatten in diastole, giving the LV the appearance of letter D (9).

Bioimpedance analysis (BIA) can estimate the water content and composition of the body by alternating current flow using the electrical characteristics of the human tissue and measuring the resistance values. Extracellular water (ECW), intracellular water (ICW), and total body water (TBW) contents can all be obtained, using the BIA. By calculating the ECW/TBW and ECW-to-body weight ratios, dry weight can be estimated (12).

Objectives

This study aims to evaluate the agreement between POCUS and clinical standard care findings in assessing the volume status in maintenance hemodialysis patients, while using BIA as a reference.

Patients and Methods

This is a cross-sectional study (diagnostic study) conducted on 45 ESRD patients on maintenance hemodialysis at Ain Shams university hospitals over 6 months, excluding those with decompensated liver disease, ascites, heart failure, active infection, or pregnancy. The sample size was determined a priori using Power Analysis and Sample Size Software (PASS), version 15.0.10, setting power at 80% and alpha error at 0.05. Previous studies were also used to estimate the sample size. Before the commencement of the study, the local ethical committee of faculty of medicine, Ain Shams university, approved the study protocol. Written informed consent was obtained from each participant.

Patients with ESRD were evaluated (clinically and with the POCUS and BIA) 30 minutes before and after a mid-week hemodialysis session.

Clinical volume status was evaluated by blood pressure, jugular venous pressure, edema, pulmonary auscultation, weight change, and symptoms review. Dry weight, determined by clinical evaluation, was defined as the lowest post-dialysis weight safely maintained with minimal signs and symptoms of volume depletion or overload. It was determined by treating nephrologists blinded to BIA-derived measurements. Clinical excess weight (i.e. ultrafiltration prescribed for the patient) was then calculated as follows; Pre-dialysis weight – Dry weight assessed by clinical examination. Besides, body mass index (BMI) was also determined by dividing the dry weight (kg) by the square of the height (m^2) (13). Lung ultrasound was performed using POCUS by an operator blinded to both the clinical assessment and the bioimpedance results. The total B-line count was obtained pre- and post–dialysis, using the 28-zone scanning technique while keeping the patient in a supine position. A standardized LUS protocol was used, in which both hemi-thoraces were scanned along predefined parasternal, midclavicular, anterior axillary and mid-axillary lines. A total of 28 zones were examined, covering the second to fourth intercostal spaces on the left side and the second to fifth on the right. The sum of the B-lines from each intercostal area was used to calculate the B lines score.

FOCUS was also performed independently by a second blinded operator, a cardiologist, to measure the IVC diameter and the degree of collapsibility, using the sub-xiphoid view with M-mode imaging while keeping the

patients in a supine position. An image of the IVC as it joins the right atrium (RA) was captured. Maximum expiratory and minimum inspiratory IVC diameters were recorded, and the IVC collapsibility index was calculated (14). The following formula was used to determine the IVC collapsibility index (CI): *IVC CI = [(maximum diameter on expiration-minimum diameter on inspiration)/ maximum diameter on expiration)] ×100)* (15).

Right ventricular dimensions were assessed in the left lateral decubitus position. Apical four-chamber (A4C) B-mode images were acquired at end-diastole. At the level of the tricuspid valve annulus, the basal RV dimension was measured. To determine the maximum transverse width of the RV basal third, calipers were positioned between the RV free wall and the interventricular septum. The mid-cavity level was used to measure the mid-RV dimension. Distance between RV free wall and interventricular septum perpendicular to the long axis was then measured. Longitudinal RV dimension was measured from the tricuspid annulus (basal level) to the RV apex along the RV free wall.

Left ventricular dimensions were assessed during the FOCUS examination in left lateral decubitus position. The parasternal long-axis M-mode view was obtained by placing the probe at the left parasternal region in the 3rd or 4th intercostal space. The M-mode cursor was aligned perpendicular through the left ventricle at the level of the mitral valve leaflet tips, allowing visualization of the interventricular septum and posterior wall motion. The left ventricular end-diastolic dimension (LVEDD) and left ventricular end-systolic dimension (LVESD) were measured, and the ejection fraction (EF) was subsequently estimated.

In our study, BIA was performed on all the patients while using a tetra-polar Maltron BioScan 916 that uses single frequency at 50 kHz. Height (in meters) was measured using a measuring tape with the patients barefoot, standing straight in the Frankfort plane with their heels pressed together. Body weight in kilograms was measured with participants wearing light clothing and without footwear (16). To avoid interference, limbs in the measurement field were cleared of metal items such as watches and bracelets. Before attaching the electrodes, the skin was cleaned with alcohol and left to dry. On one side of the body, electrodes were placed at four sites (wrist, dorsum of the hand, foot and ankle) before being connected to the impedance meter. BIA served as a reference in this study (17). Dry weight was calculated by BIA and BIA excess weight was then calculated as follows: Pre-dialysis weight- Dry weight calculated by BIA.

Statistical analysis

The collected data were coded, tabulated and analyzed statistically using IBM SPSS statistics (Statistical Package for Social Sciences) software version 28.0, IBM Corp., Chicago, USA, 2021. Quantitative data tested for normality using Shapiro-Wilk test, then described as Mean ± SD (standard deviation) as well as minimum and maximum of the range, and then compared using paired T-test. For correlations, we used Pearson's correlation test. In addition for agreement, intraclass correlation coefficient (ICC) was conducted. Meanwhile, qualitative data are described as number and percentage. Moreover, linear regression was conducted to find independent factors affecting BIA weight excess and its deviations from clinical and POCUS measures. A P value < 0.05 was considered significant.

Results

The mean ± SD of age was 42.2 ± 13.9 years and BMI was 25.8 ± 5.4 kg/m^2. Around 46.7% of the study population were male (Table 1).

Table 2 shows, number of B lines, IVC expiratory diameter, basal RV dimension, mid RV dimension, longitudinal RV dimension, LVESD and LVEDD significantly decreased post-dialysis, while IVC CI significantly increased post-dialysis.

As shown in Table 3, SBP and DBP significantly decreased post-dialysis. Body weight also significantly decreased post-dialysis.

Table 4 demonstrates that mean ± SD of the dry weight calculated by BIA and the excess weight (kg) by BIA were 68.3 ± 21.1 kg and 2.8 ± 1.5 kg respectively.

Table 5, Figures 1 and 2 show a significant high agreement between the clinical dry weight and BIA dry weight (reference) among the study cases. Near half

Table 1. Demographic and pre-dialysis clinical characteristics of the study population (N = 45)

Characteristics	Mean ± SD	Range
Age (years)	42.2 ± 13.9	20.0–68.0
BMI (kg/m^2)	25.8 ± 5.4	17.8–41.0
Duration of hemodialysis (years)	7.4 ± 5.9	0.3–30.0
	n	**%**
Sex		
Male	21	46.7%
Female	24	53.3%
Comorbidity		
Hypertension	30	66.7%
Diabetes mellitus	1	2.2%
COPD	11	24.4%
Ischemic heart disease	4	8.9%
Symptoms and signs		
Cough	9	20.0%
Dyspnea	17	37.8%
Lower limb edema	2	4.4%
Fine basal crepitations	6	13.3%

BMI: Body mass index, COPD: Chronic obstructive pulmonary disease.

Table 2. POCUS parameters pre- and post-dialysis (N = 45)

Parameters	Time	Mean±SD	Range	*P* value
Number of B lines	Before	18.2±10.9	4.0–35.0	<0.001*
	After	7.9±5.2	3.0–24.0	
	Change	-10.3±8.5	-29.0–1.0	
IVC expiratory diameter (mm)	Before	23.0±4.1	11.0–33.0	<0.001*
	After	19.5±3.6	9.8–27.0	
	Change	-3.5±2.6	-13.0–1.0	
IVC CI (%)	Before	25.1±9.9	10.0–42.1	<0.001*
	After	41.8±10.7	16.7–57.1	
	Change	16.7±10.5	-22.6–34.6	
Basal RV dimension (mm)	Before	33.3±4.4	27.0–50.0	<0.001*
	After	28.4±3.1	20.8–38.1	
	Change	-4.9±3.1	-12.0 – -0.8	
Mid RV dimension (mm)	Before	25.1±4.0	19.0–36.0	<0.001*
	After	19.8±3.1	14.5–27.0	
	Change	-5.3±3.5	-13.4–3.1	
Longitudinal RV dimension (mm)	Before	70.3±7.9	50.9–83.0	<0.001*
	After	62.0±7.0	48.2–73.6	
	Change	-8.3±5.3	-18.5–3.4	
LVESD (mm)	Before	37.7±5.4	28.0–47.0	<0.001*
	After	32.4±4.3	23.7–39.5	
	Change	-5.3±4.4	-15.0–5.0	
LVEDD (mm)	Before	50.4±5.7	40.0–64.0	<0.001*
	After	43.4±6.2	31.0–57.0	
	Change	-7.0±5.7	-22.0–4.0	

IVC: Inferior Vena Cava, RV: Right Ventricular, LVESD: Left Ventricular End-systolic Dimension, LVEDD: left ventricular end-diastolic dimension, IVC CI: Inferior Vena Cava Collapsibility Index. Paired T-test. * Significant.

Table 3. Clinical findings of the study population pre-and post-dialysis (N = 45)

Variables	Time	Mean±SD	Range	*P* value
SBP (mm Hg)	Before	132.4±24.2	90.0–190.0	<0.001*
	After	125.2±25.2	90.0–200.0	
	Change	-7.2±23.3	-90.0–35.0	
DBP (mm Hg)	Before	77.0±15.8	50.0–110.0	<0.001*
	After	71.3±13.2	50.0–100.0	
	Change	-5.7±13.6	-40.0–30.0	
Body weight (kg)	Before	71.1±21.1	31.5–111.6	<0.001*
	After	68.8±20.6	30.0–109.5	
	Change	-2.3±1.2	-4.5–0.0	

SBP: Systolic blood pressure, DBP: Diastolic blood pressure. Paired T-test. * Significant.

Table 4. BIA findings of the study population (N = 45)

Variables	Mean ± SD	Range
Dry weight by BIA (kg)	68.3 ± 21.1	30.0–109.0
Excess weight by BIA (kg)	2.8 ± 1.5	0.0–6.1

BIA: Bioimpedance Analysis.

(40.0%) of the deviation between the clinical and BIA was ± 0.5 kg.

Table 6 explains that multiple linear regression analyses were performed to evaluate the relationship between the estimated BIA weight excess and several POCUS parameters (measured pre- and post-dialysis). Post-dialysis reduction in B lines, post-dialysis reduction in both longitudinal RV dimension and LVEDD were all significant variables in estimating BIA weight excess. Meanwhile, post-dialysis reduction in B lines showed a positive association with BIA weight excess. ($\beta = 0.104$, $P < 0.001$). Post-dialysis reduction in both longitudinal RV dimension ($\beta = 0.091$, $P = 0.005$) and LVEDD ($\beta = 0.062$, $P = 0.037$) also showed a significant positive association with BIA weight excess. The estimation equation could explain 50.9% of the variability of BIA weight excess. A prediction equation of the estimated weight excess by BIA was as follows: estimated BIA weight excess (kg) =

Table 5. Accuracy and agreement between clinical dry weight and BIA dry weight (reference) among the study population (N = 45)

Characteristics	Median (1st–3rd IQR)	Range
Difference (Clinical – BIA)	0.5 (-0.2–1.3)	-1.8–4.3
	n	**%**
Accuracy		
< -2.0 kg	0	0.0%
-2.0 – -1.1 kg	3	6.7%
-1.0 – -0.6	4	8.9%
±0.5 kg	18	40.0%
0.6 – 1.0 kg	7	15.6%
1.1 – 2.0 kg	6	13.3%
> 2.0 kg	7	15.6%
	ICC	***P* value**
Agreement	0.998	<0.001*

BIA: Bioimpedance analysis, IQR: Interquartile range, ICC: Intraclass correlation coefficient. *Significant.

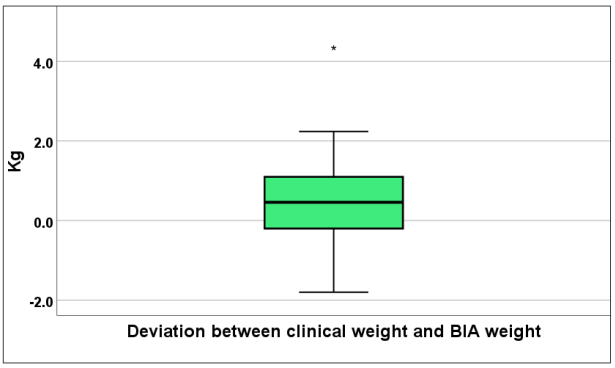

Figure 1. Deviation between clinical dry weight and BIA dry weight (reference) among the study cases.

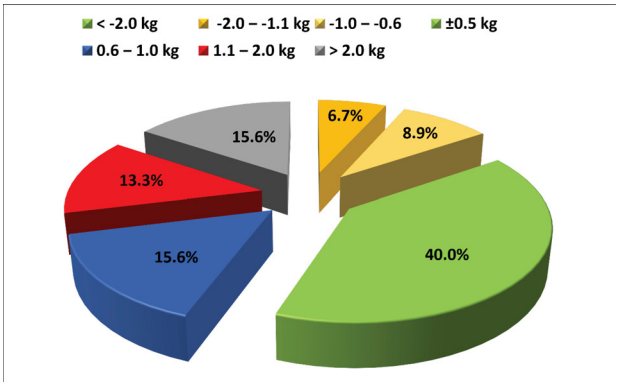

Figure 2. Agreement between clinical dry weight and BIA dry weight (reference) among the study cases.

2.940 + 0.104 (B lines reduction) + 0.091 (longitudinal RV reduction (mm)) + 0.062 (LVEDD Reduction (mm)).

Table 7 shows that clinical excess weight, post-dialysis reduction in both longitudinal RV dimension and LVESD were all significant variables in estimating BIA weight excess. The prediction equation could explain 54.2% of the variability of BIA weight excess. The prediction equation was as follows; estimated BIA weight excess (kg) = 2.585+0.709 (clinical weight) + 0.102 (longitudinal RV dimension reduction (mm)) + 0.094 (LVESD reduction (mm)).

Table 8, Figures 3 and 4 show that POCUS prediction had higher prediction and accuracy than clinical estimation. Besides, combination of both POCUS prediction and clinical prediction had the highest agreement and accuracy.

Discussion

For nephrologists, assessing the volume status is a crucial skill that is essential for managing acute kidney injury and ESRD, as well as treating hypertension and electrolytes disorders (4).

Table 6. Linear regression model estimating weight excess by BIA using POCUS parameters (N = 45)

Factors	β	SE	*P* value	95% CI	R^2
Constant	2.940	0.423	<0.001*	2.086–3.794	50.9%
Post-dialysis reduction in B lines	0.104	0.019	<0.001*	0.065– 0.142	
Post-dialysis reduction in longitudinal RV dimension (mm)	0.091	0.030	0.005*	0.030–0.152	
Post-dialysis reduction in LVEDD (mm)	0.062	0.029	0.037*	0.004–0.120	

RV: Right ventricular, LVEDD: Left ventricular end-diastolic dimension, β: Regression coefficient, SE: Standard error, CI: Confidence interval, R^2: Coefficient of determination.

Table 7. Linear regression model estimating BIA weight excess using clinical and POCUS parameters (N = 45)

Factors	β	SE	*P* value	95% CI	R^2
Constant	2.585	0.441	<0.001*	1.694–3.476	54.2%
Clinical excess weight	0.709	0.126	<0.001*	0.455–0.964	
Post-dialysis reduction in longitudinal RV dimension (mm)	0.102	0.029	0.001*	0.044–0.161	
Post-dialysis reduction in LVESD (mm)	0.094	0.035	0.011*	0.023–0.165	

RV: Right ventricular, LVESD: Left ventricular end-systolic dimension, β: Regression coefficient, SE: Standard error, CI: Confidence interval, R^2: Coefficient of determination.

Table 8. Accuracy and agreement between BIA estimation (reference) and each of clinical, POCUS predicted and clinical and POCUS predicted estimation among the study cases (N = 45)

Characteristics		Clinical (ultrafiltration)	POCUS prediction	Clinical & POCUS prediction
Agreement	Mean±SD	2.2±1.2	2.8±1.0	2.8±1.1
	Range	0.0–4.5	0.7–5.3	0.5–4.8
	ICC	0.726	0.806	0.826
	P value	<0.001*	<0.001*	<0.001*
Difference (method- BIA)	Median (1st–3rd IQR)	-0.4 (-1.1–0.2)	0.0 (-0.5–0.5)	-0.1 (-0.6–0.7)
	Range	-4.3–1.8	-2.6–2.4	-2.0–2.2
	< -2.0 kg	7 (15.6%)	2 (4.4%)	0 (0.0%)
	-2.0 – -1.1 kg	5 (11.1%)	4 (8.9%)	4 (8.9%)
	-1.0 – -0.6	8 (17.8%)	4 (8.9%)	3 (6.7%)
	±0.5 kg	19 (42.2%)	25 (55.6%)	29 (64.4%)
	0.6 – 1.0 kg	5 (11.1%)	1 (2.2%)	5 (11.1%)
	1.1 – 2.0 kg	1 (2.2%)	8 (17.8%)	3 (6.7%)
	> 2.0 kg	0 (0.0%)	1 (2.2%)	1 (2.2%)

POCUS: Point-of-Care Ultrasound, BIA: Bioimpedance analysis, ICC: Intraclass correlation coefficient, IQR: Interquartile range.
Intraclass correlation coefficient between BIA estimated weight and each of the clinical, POCUS predicted, and combined clinical and POCUS predicted weight estimates. * Significant.

The diagnostic accuracy of routine clinical examination of fluid status is poor, necessitating the need for additional tools to assess the patients' volume status; given that pulmonary congestion is a subtle process that develops weeks before the onset of severe symptoms (18).

In our present study, the mean number of B lines was 18.2 ± 10.9 pre-dialysis and decreased significantly to 7.9 ± 5.2 post-dialysis with $P < 0.001$, indicating effective ultrafiltration. Similarly, Zheng et al (19) reported a significant reduction in the number of B-lines post-dialysis from a median of 15 [9, 26] pre-dialysis to 5 [2, 10] post-dialysis with a $P < 0.001$.

Our study showed a significant post-dialysis reduction in the IVC expiratory diameter from 23.0 ± 4.1 mm to 19.5 ± 3.6 mm with a $P < 0.001$, which is consistent with the expected intravascular volume depletion. These findings align with those of Torterüe et al (20), who conducted a single-center prospective study analyzing 48 hemodialysis sessions in 16 patients to evaluate the relationship between pre-dialysis IVC diameter, hydration status assessed by physicians and bioimpedance spectroscopy (BIS). Their study also reported a significant reduction in the expiratory IVC diameter following hemodialysis in pediatric patients, with a median decrease of 3.17 mm [−4.62; −1.73] with a $P < 0.0001$.

On the other hand, the study by Mohammad et al (21), showed that post-ultrafiltration reductions in IVC expiratory diameter (from 17.1 ± 15 mm to 16.2 ± 13.9 mm) did not reach a statistical significance ($P = 0.296$). Several factors may account for this discrepancy, including differences in patient characteristics, ultrafiltration volume, timing of IVC measurements, or measurement technique. Notably, their study focused on a slightly smaller sample size of 38 patients and included a broader mix of volume statuses, without strict exclusion of cardiac comorbidities, which can significantly affect venous compliance and central pressure dynamics. Moreover, their mean pre-dialysis IVC diameter was lower (17.1 ± 15

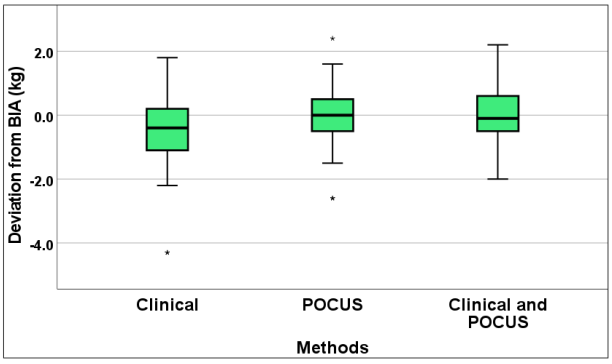

Figure 3. Deviation between BIA estimation (reference) and each of clinical, POCUS predicted and clinical and POCUS predicted estimation among the study cases.

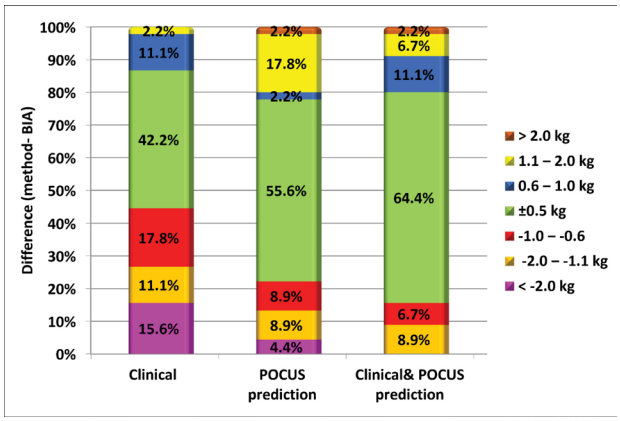

Figure 4. Accuracy of clinical, POCUS predicted and clinical and POCUS predicted estimation among the study cases.

mm), with an unusually large standard deviation- nearing the mean, suggesting considerable measurement variability or heterogeneity in patient volume status. In contrast, our cross-sectional study had a higher baseline IVC diameter (23.0 ± 4.1 mm), indicating a uniform state of volume overload and greater capacity for measurable reduction post-ultrafiltration. Additionally, the timing and technique of IVC measurement were not clearly standardized in their study, while we ensured measurements were performed at least 30 minutes before and after dialysis, potentially contributing to more reliable results. Indeed, Katzarski et al (22) suggested that performing IVC assessment two hours post-dialysis (so that re-equilibration between the compartments has taken place) might yield better results.

In our present study, the IVC collapsibility index (IV CI) increased significantly following dialysis, from 25.1 ± 9.9% before dialysis to 41.8 ± 10.7% after dialysis with a $P < 0.001$, indicating effective ultrafiltration. Likewise, Hafiz et al (23) evaluated 40 regular hemodialysis patients pre- and post-dialysis, assessing IVC CI and they reported a significant post-dialysis increase in IVC CI ($P < 0.001$)

On the other hand, Vitturi et al (24) found that although the IVC diameters decreased post-dialysis, the IVC CI did not increase significantly. This might be because they included patients with mild heart failure (New York Heart Association class I–II). Even if these patients were stable, their heart condition could still cause higher pressures in the RA, so the IVC stayed less collapsible. In our study, we excluded heart failure patients, which might explain why we saw a clearer increase in IVC CI post-dialysis.

Following dialysis, our study demonstrated that the LVESD and LVEDD significantly decreased from 37.7 ± 5.4 mm and 50.4 ± 5.7 mm to 32.4 ± 4.3 mm and 43.4 ± 6.2 mm, respectively ($P < 0.001$ for both). These reductions are primarily attributed to the decrease in preload resulting from ultrafiltration, which lowers intravascular volume and reduces left ventricular filling during diastole and contraction during systole.

While our study explored echocardiographic changes in a non-heart failure ESRD population, Kim et al (25) enrolled 54 ESRD patients, and assessed them for heart failure (pre- and post-hemodialysis) based on the European Society of Cardiology criteria, including symptoms, elevated N-terminal pro-B-type natriuretic peptide, and echocardiographic abnormalities. Similar to our study, Kim et al (25) reported that LVEDD significantly decreased from 52.0 ± 7.2 mm to 47.1 ± 6.3 mm ($P < 0.001$), and LVESD significantly decreased from 34.3 ± 6.8 mm to 31.0 ± 5.4 mm ($P = 0.006$) following dialysis. However, our study demonstrated a slightly more pronounced reduction in both LVEDD and LVESD, which may be due to the exclusion of heart failure patients, potentially allowing for greater cardiac responsiveness to volume shifts.

Taking a different approach, Zheng et al (19) carried out a cross-sectional study in which Zhejiang Provincial People's Hospital maintenance hemodialysis patients were categorized according to the level of lung congestion based on B-line counts (<16, 16–30, >30) prior to hemodialysis. In their study, no significant differences in LVEDD were found among the groups ($P > 0.05$). This suggested that LVEDD might not be a sensitive marker for pulmonary fluid overload when compared cross-sectionally, using LUS classification.

While most previous studies have primarily assessed the basal RV dimension, our study is among few to evaluate all three standard RV dimensions (basal, mid, and longitudinal) both pre- and post-hemodialysis. This comprehensive approach allows for a more complete understanding of RV remodeling and its response to volume shifts during dialysis. Following hemodialysis, we observed a statistically significant reduction across all RV dimensions: basal RV dimension decreased from 33.3 ± 4.4 mm to 28.4 ± 3.1 mm, mid RV dimension from 25.1 ± 4.0 mm to 19.8 ± 3.1 mm, and longitudinal RV dimension from 70.3 ± 7.9 mm to 62.0 ± 7.0 mm (all with $P < 0.001$).

A study by Georgianos et al (26) conducted two-dimensional echocardiography in 41 maintenance hemodialysis patients before and after their first and second weekly sessions. Similarly, they observed a significant reduction post-dialysis in RV end-diastolic diameter (RVEDD) (presumably referring to the basal RV dimension, given standard echocardiographic practice). During the first session, it decreased from 34.7 ± 9.7 mm to 30.9 ± 8.3 mm ($P < 0.001$), and during the second session, from 34.0 ± 8.3 mm to 31.0 ± 8.8 mm ($P < 0.001$), reinforcing the consistent impact of fluid removal/preload decrease on RV dimensions. Consistent with both our findings and those of Georgianos et al (26) and Palecek et al (27) also reported a significant decline in RVEDD from 36 ± 6 mm to 33 ± 6 mm after dialysis ($P < 0.001$).

The estimated dry weight by BIA in our study was 68.3 ± 21.1 kg, ranging from 30.0 to 109.0 kg. In our present study, we defined excess weight by BIA as the difference between the pre-dialysis weight and the BIA-estimated dry weight, reflecting the degree of fluid overload before dialysis. Our study had a mean excess weight by BIA of 2.8 ± 1.5 kg, ranging from 0.0 to 6.1 kg. In our cross-sectional study, there was excellent agreement between clinical and BIA-derived dry weight, with a very high ICC of 0.998 ($P < 0.001$). Notably, the majority of our patients exhibited either a minimal difference between clinical and BIA-derived dry weights (± 0.5 kg in 40%) or a clinically significant overestimation by the clinical method (>0.5 kg in 44.4%). This distribution suggests a consistent trend toward higher clinical dry weight estimates compared to those obtained via BIA, indicating that BIA tended to yield lower dry weight values overall. This aligns with the study conducted by Jian et al (28), who evaluated dry weight estimation in maintenance hemodialysis patients using BIA compared with clinical assessment. Their study demonstrated that one bioimpedance-derived method estimated significantly lower dry weight (62.0 ± 16.1 kg)

than the clinically determined dry weight was significantly lower than the (63.1 ± 16.1 kg) with a $P < 0.05$.

In our study, B-lines reduction emerged as a significant predictor of excess weight by BIA ($P < 0.001$), highlighting its utility in assessing volume overload. This demonstrated that post-dialysis B-lines reduction was significantly linked to how much excess weight the patient had before dialysis, based on BIA. Applying a different method, Vitturi et al (24) assessed the volume status of hemodialysis patients by measuring the intradialytic weight loss and similarly reported a significant correlation between the post-dialysis B-lines reduction and the weight loss ($\beta = 0.36$, $P = 0.007$). Both studies signify the clinical relevance of LUS in guiding volume management in terms of weight in hemodialysis patients. However, Zheng et al (19), who conducted a cross-sectional study on 98 maintenance hemodialysis patients, using LUS and BIA to assess volume status pre- and post-dialysis, found that despite the number of B-lines showing a statistically significant positive correlation before and after hemodialysis with the ECW ($P = 0.03$ pre-dialysis; $P = 0.013$ post-dialysis) and the ECW/TBW ratio ($P = 0.028$ pre-dialysis; $P = 0.031$ post-dialysis), it did not correlate with TBW ($P = 0.218$ pre-dialysis; $P = 0.92$ post-dialysis). Furthermore, the change in B-lines did not have a significant correlation to the ultrafiltration volume. ($r = –0.043$, $P = 0.671$). We argue that B-lines are significantly associated with systemic fluid overload as estimated by BIA, supporting their role as a marker of extracellular volume status. The lack of correlation with the ultrafiltration and TBW in Zheng et al (19) study may reflect that B-lines primarily represent extravascular lung water rather than intravascular volume changes.

On the other hand, in both our study and Vitturi et al (24) IVC diameters reduction, were not significantly associated with BIA excess weight or intradialytic weight loss, respectively. One possible explanation is that LUS and IVC measurements provide insight into separate fluid compartments. While IVC diameter mainly represents intravascular changes, B-lines represent the extravascular pulmonary congestion. As a result, early post-dialysis IVC measurements (in our study, IVC diameters were measured 30 minutes after hemodialysis) may underestimate the true fluid removal due to ongoing fluid shifts.

Additionally, our study showed via linear regression analyses that post-dialysis reductions in RV longitudinal dimension, LVEDD, and B-lines are all significant predictors of excess weight by BIA in the POCUS model ($P = 0.005$, $P = 0.037$ and $P \leq 0.001$, respectively), whereas post-dialysis reductions in RV longitudinal dimension, LVESD and the clinical estimated weight predicted the excess weight by BIA in the combined clinical and POCUS model ($P = 0.001$, $P = 0.011$ and $P < 0.001$, respectively).

However, the POCUS model and the combined clinical and POCUS model explained 50.9% and 54.2% of the variability in BIA-estimated weight excess, respectively, suggesting that additional determinants may contribute to volume status assessment. While POCUS and clinical parameters are valuable predictors of volume excess, factors such as intracellular fluid shifts, nutritional status, and vascular tone may also influence fluid distribution.

Undeniably, clinically estimated excess weight (defined in our study as the difference between the pre-dialysis weight and the clinically estimated dry weight) was significantly associated with the BIA-estimated weight excess ($\beta = 0.709$, $P < 0.001$), indicating that clinical assessment of volume status is a strong predictor of fluid overload. Thus, mutually reinforcing the excellent agreement between the clinical and BIA-derived dry weight, with a very high ICC of 0.998 ($P < 0.001$).

In our present study, we uniquely compared the accuracy and agreement of three different methods for estimating volume status [clinical assessment (translated into the prescribed ultrafiltration), significant POCUS parameters, and a combined clinical and POCUS approach] against BIA (BIA estimated excess weight), which served as the reference standard.

In our study, the combination of clinical assessment and POCUS yielded the highest agreement with the BIA-estimated excess weight (ICC = 0.826, $P < 0.001$). It also had the highest accuracy, with 64.4% of patients having a weight difference of 0.5 kg or less compared to the BIA measurement.

POCUS-based prediction ranked second to the combination, demonstrating higher agreement with BIA estimates (ICC = 0.806, $P < 0.001$) compared to clinical assessment alone (ICC = 0.726, $P < 0.001$). It also showed greater accuracy, with 55.6% of patients falling within ± 0.5 kg of BIA-estimated weight, versus only 42.2% with clinical assessment alone. Overall, these findings suggest that while both physical examination and POCUS require operator skill, POCUS offers clearer, measurable signs of overhydration, making its results more reliable than clinical assessment alone.

While both the clinical and combined methods had no cases of overestimation >2.0 kg, the combined method in our study also eliminated underestimations worse than -2.0 kg, which were still present in clinical alone (15.6%) and POCUS alone (4.4%). This suggests that combining clinical assessment with POCUS may reduce the risk of extreme misclassification, particularly extreme underestimation of fluid excess.

Although several studies have evaluated POCUS, BIA, and clinical assessment separately in volume status assessment in hemodialysis patients, to the best of our knowledge, none have directly assessed the agreement between all three modalities in the specific manner undertaken in our study.

Our findings are consistent with those of Malhotra et al (29) whose aim was to compare the efficacy of clinical assessment, LUS, and BIS in evaluating fluid volume status in hemodialysis patients. 40% of their patients had exhibited residual volume overload post-dialysis

on BIS and 35% had persistent pulmonary congestion on LUS, despite being considered clinically euvolemic. This discrepancy underscores the limitations of clinical examination alone in detecting subclinical fluid overload.

In alignment with our findings, Vareesangthip et al (30) demonstrated the limited reliability of clinical assessment in detecting early or mild volume overload, where clinical edema or lung crackle had low sensitivity (20-32%) to detect extravascular lung water excess even among patients with mild-to-moderate or severe pulmonary congestion, as stratified by ultrasound lung comet (ULC) scoring. Overhydration assessed by BIA was found in 75% and 64.3% of patients with mild-to-moderate and severe ULC, respectively. Despite this, that study did not explore the potential complementary value of combining all other POCUS variables(including IVC assessment or echocardiography) with the clinical examination, as we did.

Chang et al (31) conducted out a prospective study involving hospitalized hemodialysis patients to evaluate how accurately LUS can assess extracellular fluid status, using BIS as the reference standard, and comparing it separately with physical examination findings. Against our findings, their study showed that post-dialysis LUS findings agreed poorly with both BIA (62%; $\kappa = 0.11$) and clinical examination (66%; $\kappa = 0.022$), indicating poor concordance beyond chance in hospitalized patients.

The weaker agreement in the hospital-based study may be due to acute fluid shifts and unstable conditions (such as active infections, recent surgeries, intravenous fluid administration, and use of vasoactive medications) unlike our study, which included stable, non-critical outpatients.

Conclusion

Our study demonstrates that the integration of clinical assessment with POCUS provides a more reliable approach for assessing volume status in hemodialysis patients compared to either method independently.

Limitations of the study

Several limitations should be considered when interpreting our findings. Generalizability to a broader hemodialysis population may be limited by the study's single-center design and modest sample size. The operator dependent nature of POCUS could have introduced measurement variability despite standardization. Additionally, although single-frequency BIA is a valid and widely used method, multi-frequency BIA or BIS may provide a more detailed assessment of extracellular and intracellular fluid compartments.

Authors' contribution

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Conflicts of interest

The authors declare that they have no competing interests

Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

Ethical issues

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human participants. The research protocol was reviewed and approved by the Ethics Committee of the Faculty of Medicine, Ain Shams University, Cairo, Egypt (Approval Code: FMASU MD194/2023; approved on 17 August 2023). Written informed consent to participate in the study was obtained from all participants and/or their parents or legal guardians prior to enrollment. Participant confidentiality and anonymity were strictly maintained throughout the study and publication process

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