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Original Article

Chest Ultrasound as a New Tool for Assessment of Volume Status in Hemodialysis Patients

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ABSTRACT. Accurate assessment of volume status (VS) in hemodialysis (HD) patients is challenging. The use of chest ultrasound (CUS) for detection of extravascular lung water has recently gained wide acceptance. The aim of this study was to evaluate the use of CUS in VS assessment in HD patients in comparison to clinical and inferior vena cava (IVC) indices and to assess their relation with volume displacement after ultrafiltration. This prospective cohort study was carried out on 38 patients on regular HD. VS was assessed using a 13-point clinical score, and IVC indices and CUS score were measured pre- and post-ultrafiltration. Correlation between these parameters and with ultrafiltration volume was tested. There was a statistically significant reduction in post-ultrafiltration CUS score and the 13-point clinical score (P <0.01). Moreover, reduction in all the IVC indices (inspiratory and expiratory diameters and collapsing index) was detected, but did not reach statistical significance (P = 0.185, P = 0.296, and P = 0.194, respectively). CUS score had statistically significant correlations with ultrafiltration volume and New York Heart Association classes (P <0.001 and <0.001, respectively). Neither clinical signs nor IVC indices can be used independently for the assessment of VS in HD patients. CUS is a useful guide in VS assessment, and we recommend its routine use in the management of HD patients. Concomitant use of bio-impedance analysis (BIA) may be needed in addition to CUS for more accurate assessment of VS in HD patients.

Introduction

Volume overload is a major, subtle risk factor and independent predictor for all-cause mortality as well as cardiovascular death in hemodialysis (HD) patients.[1-3] However, accurate assessment of volume status (VS) in HD patients is one of the greatest challenges.[4] Clinical assessment of VS by measurement of blood pressure, central venous pressure, and signs of edema has limitations.[5-8] Assistive methods, such as plasma volume changes across dialysis by the Crit-Line system and circulating levels of cardiac natriuretic peptides, offer an opportunity to improve the inaccuracy of the clinical methods, however all these methods still have a

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low evidentiary basis to support their use in HD patients.[9] The use of chest ultrasound (CUS) for detection of extravascular lung water (EVLW) in intensive care patients[10] and in patients with heart failure has recently gained acceptance.[11] EVLW is reflected by CUS as B lines (comet tail artifacts) which are defined as laser-like vertical reverberation artifacts that arise from the pleural line and extend to the end of the screen without fading and moving in synchrony with lung movement. B lines have been explained by thickening of the interlobular septae which becomes reflected on the lung pleural interface due to difference in the acoustic impedance between the thickened interstitium and that of the air in the surrounding lung. It is well known that B lines are correlated to left ventricular capillary wedge pressure.[12]

The aim of this study was to evaluate the use of CUS in VS assessment in HD patients in comparison to clinical signs and inferior vena cava (IVC) indices and to assess their relation with volume displacement after ultrafiltration.

Patients and Methods

Study population

This prospective cohort study was carried out on 38 patients who were under regular HD in the Nephrology Unit of Assiut University Hospital in the period from January 2018 to September 2018. Patients with primary lung disorders were excluded from the study. Written consents were obtained from all participants, and the study was approved by the ethical committee of faculty of medicine of Assiut University.

Demographic, clinical, and laboratory data

Demographic data, medical history, and comorbid diseases were recorded. Body mass index (BMI) was calculated as weight (kg)/height^2 (m). Venous blood samples were collected for the measurement of serum levels of creatinine, blood urea nitrogen (BUN), urea (mg/dL), hemoglobin (g/dL), serum electrolytes, and serum albumin level.

13-point clinical score assessment

A clinical score of 13 points including signs and symptoms of volume overload was postulated in order to clinically evaluate systemic hydration state. This score included systolic blood pressure (BP) >140, diastolic BP >90, respiratory rate >25, orthopnea, high JVP, basal crepitation, lower limb edema, ascites, pleural effusion, and New York Heart Association (NYHA) score (Table 1). Each patient was evaluated by two independent resident nephrologists before and 4–6 h after dialysis. The percentage change of that score was calculated using the following equation = [(predialysis clinical score – postdialysis clinical score)/predialysis clinical score] × 100%.

Chest ultrasonographic assessment

All CUS examinations were performed using Samsung Medison Co. Ltd., 3.5 MHz convex probe (Republic of Korea). CUS was performed in all patients before and 4–6 h after HD. B-lines were recognized and noted. Ultrasound examination of the anterolateral chest was carried out of the right and left hemi-thoraces, from the second to the fourth (on the right side to the fifth) intercostal space. In each intercostal space, the number of B-lines was counted at the parasternal, midclavicular, anterior axillary, and midaxillary lines for a total of score of 28, named CUS score.

The percentage change was calculated using the following equation: [(predialysis B score – postdialysis B score)/predialysis B score] × 100%.[10]

Inferior vena cava assessment

Samsung Medison Co. Ltd., 3.5 MHz convex probe was used to measure IVC diameter. The probe was placed in the subxiphoid location while the patients were in the supine position. Measurement was made 2 cm caudal to the junction point of the hepatic veins and IVC. We measured both the inspiratory and expiratory diameters by measuring IVC lumen from one interior wall to the opposite interior wall during a single respiratory cycle. The IVC collapsibility index (IVCCI) was calculated by the

Table 1. Pre- and post-ultrafiltration clinical score of the study population.

Score items	Pre-ultrafiltration *n* (%)	Post-ultrafiltration *n* (%)	*P*
Systolic BP >140	11 (28.9)	5 (13.1)	<0.001
Diastolic BP >90	9 (23.6)	6 (15.8)	0.039
RR >25	13 (34.2)	8 (21.0)	<0.001
Orthopnea	7 (18.4)	0 (0)	-
High JVP	10 (26.3)	9 (23.6)	0.198
Basal crepitation	7 (18.4)	0 (0)	-
Lower limb edema	9 (23.7)	8 (21.0)	0.324
Ascites	11 (28.9)	11 (28.9)	-
Pleural effusion	11 (28.9)	11 (28.9)	-
NYHA score			
I	11 (28.9)	5 (13.1)	<0.001
II	14 (36.8)	7 (18.4)	<0.001
III	6 (15.8)	2 (5.2)	<0.001
IV	7 (18.4)	0 (0)	-

Total score of 13 points. BP: Blood pressure, RR: Respiratory rate, JVP: Jugular venous pressure, NYHA: New York Heart Association.

following equation: IVC expiratory diameter – IVC inspiratory diameter/IVC expiratory diameter × 100%. IVC diameter was measured before and 4–6 h after HD, and the percentage change was calculated using the following equation: predialysis IVCCI – postdialysis IVCCI/pre-dialysis IVCCI×100%.

Hemodialysis/Ultrafiltration volume assessment

HD was performed using Fresenius 4008 therapy system (Fresenius Medical Care, North America, Walnut Creek, CA). The duration of dialysis treatment was on average, 4 h. Dialysate temperature was kept constant at 37°C with dialysate ion-concentrations consisting of sodium 135 mmol/L, bicarbonate 38 mmol/L, potassium 1.5 mmol/L, and calcium 1.25 mmol/L. Filters used were PF 170 or PF 210 from Gambro (Lund, Sweden). The average blood flow was 300 mL/m. The dialysate flow was set at 500 mL/m. Ultrafiltration volumes were assessed by a resident nephrologist according to the standard protocols of Assiut University HD unit.

Statistical Analysis

The statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 19.0 (SPSS Inc., Chicago, IL, USA). Kolmogorov–Smirnov test was used to test normality. Continuous variables were presented as the means ± standard deviation and categorical variables were presented as percentages. Mann–Whitney test was used to compare quantitative variables between groups. Spearman's correlation was done to measure correlation among qualitative variables. Pearson's correlation was done to mea-sure correlation among quantitative variables. P <0.05 was considered statistically significant.

Results

Demographic, clinical, and laboratory data

The studied patients had regular HD through arteriovenous fistula where 55% of them had brachio-cephalic fistulae, 30% had brachio-basilic transposition, and 15% had radial-cephalic fistulae. Insulin therapy accounted for 73% of anti-diabetic therapy. Only 24% of patients, who had average urine output of 1.25 ± 0.75 L/day, received loop diuretics in their anti-hypertensive medications. The average interdialytic weight gain was 3.57 ± 0.75 kg. Other demographic, clinical, and laboratory data of the study population are shown in Table 2.

Table 2. Demographic, clinical, laboratory, and ultrafiltration data of the study patients.

Parameter	Mean±SD /No. (38)	Median (range)/%
Age (years)	46.68±14.57	49.00 (21.00–70.00)
Female sex (Number and %)	12	31.6%
DM (Number and %)	8	21.1%
HTN (Number and %)	18	47.4%
SBP (mm Hg)	137.11±30.84	130.00 (80.00–200.00)
DBP (mm Hg)	84.08±15.76	90.00 (40.00–110.00)
RR (cycle/min)	20.18±6.00	18.50 (13.00–33.00)
HR (beat/min)	76.61±11.34	77.00 (50.00–110.00)
BMI (kg/m^2)	25.51±6.25	24.33 (13.84–45.79)
Urea (mg/dL)	42.43±20.72	38.05 (11.00–100.00)
Creatinine (µmol/L)	967.47±478.54	874.00 (345.00–2420.00)
Hb (g/dL)	8.43±1.84	8.10 (5.00–12.70)
Albumin (mg/dL)	3.26±0.72	3.35 (1.20–4.60)
Na (mmol/L)	135.74±6.12	135.00 (124.00–152.00)
K (mmol/L	4.02±0.55	4.00 (3.30–5.50)
Ultrafiltration (L)	1.83±1.38	0.75 (0.00–5.00)

DM: Diabetes mellitus, HTN: Hypertension, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, HR: Heart rate, RR: Respiratory rate, BMI: Body mass index, HB: Hemoglobin.

Post-ultrafiltration versus indices changes

There were statistically significant reductions in systolic BP (*P* = 0.001), diastolic BP (*P* = 0.039), respiratory rate (*P* <0.001), and all NYHA classes (*P* <0.001) with no recorded post-ultrafiltration orthopnea.

CUS scores and clinical score showed statistically significant post-ultrafiltration reduction (*P* <0.001 and <0.001, respectively) (Table 1). However, post-ultrafiltration reductions in IVC indices did not reach statistical significance (*P* = 0.185, *P* = 0.296, and *P* = 0.194) (Table 3).

Correlation data

There was no statistically significant correlation between the clinical score, IVC indices, CUS score (both pre- and post-ultrafiltration) and their percent changes (Tables 4-6). However, the CUS score had a statistically significant correlation with ultrafiltration volume (Table 7 and Figure 1) and NYHA classes (*P* <0.001, *P* <0.001, respectively) (Table 8 and Figures 2, 3).

Discussion

Maintenance of hydration status in HD patients is a challenging task and has no established valid method for setting it.[8] The aim of this study was to evaluate the use of CUS in

Table 3. Different methods of assessment of volume status pre- and post-ultrafiltration of the study population.

Variables	Pre-ultrafiltration Mean±SD	Post-ultrafiltration Mean±SD	*P*
Clinical score	3.47±2.51	1.28±1.27	<0.001
% changes of clinical score	59.19±32.77		
IVC/inspiratory D. (cm)	1.02±0.76	0.93±0.90	0.185
IVC/expiratory D. (cm)	1.71±1.50	1.62±1.39	0.296
IVCCI	0.38±0.24	0.45±0.28	0.194
% changes IVCCI	0.15±0.59		
B lines score	10.32±6.22	4.42±3.85	<0.001
% changes of B lines score	32.59±32.13		

IVC: Inferior vena cava, IVCCI: IVC collapsibility index, D: Diameter, SD: Standard deviation.

Table 4. Pre-ultrafiltration correlations.

Parameter		Clinical score	IVCCI	CUS score
Clinical score	*r*			
	P			
IVCCI	*r*	0.124		
	P	0.460		
CUS score	*r*	0.718	0.073	
	P	0.074	0.662	

IVCCI: Inferior vena cava collapsibility index, CUS: Chest ultrasound.

Table 5. Post-ultrafiltration correlations.

Parameter		Clinical score	IVCCI	CUS score
Clinical score	*r*			
	P			
IVCCI	*r*	0.002		
	P	0.989		
CUS score	*r*	0.272	0.142	
	P	0.099	0.394	

IVCCI: Inferior vena cava collapsibility index, CUS: Chest ultrasound.

Table 6. Percentage changes; correlation of different volume status tools.

Parameter		Clinical score %	IVCCI %	CUS % change
Clinical score % changes	*r*			
	P			
IVCCI % changes	*r*	0.223		
	P	0.179		
CUS % changes	*r*	0.487	0.253	
	P	0.049	0.125	

% changes: Percent changes, IVCCI: Inferior vena cava collapsibility index, CUS: Chest ultrasound.

VS assessment in HD patients in comparison to clinical signs and IVC indices and to assess their relation with volume displacement after ultrafiltration. We assessed the VS in our patients before and after ultrafiltration using clinical score, IVC indices, and CUS. In the current study, although there was a significant reduction in the clinical score after ultrafiltration, the percent change in the clinical score had no significant correlation with ultrafiltration volume. Moreover, the clinical score showed insignificant correlations with other VS assistive tools both pre- and post-ultrafiltration. These findings signify the poor performance of clinical signs in the assessment of VS in HD patients.

These findings were concordant with previous studies that concluded that neither individual physical sign such as jugular venous pressure (JVP), hypertension, pedal edema,[13-15] nor integrated clinical examination can accurately estimate dry weight when compared to more objective methods such as BIA[16-18] and RVP.[19,20] Systemic hypertension is a multifactorial disease. Although volume overload can explain

Table 7. Correlations between ultrafiltration volume and % changes in different VS tools.

Parameter	Ultrafiltration	
	***r*-value**	***P*-value**
Clinical score % changes	0.473	0.049
IVCCI % changes	0.172	0.301
CUS % changes	0.735	<0.001

% changes: Percent changes, VS: Volume status, IVCCI: IVC collapsibility index, CUS: Chest ultrasound.

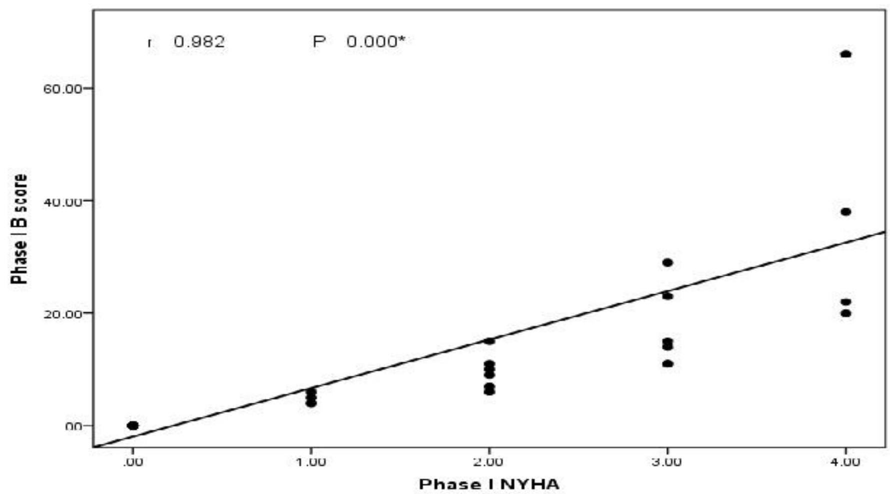

Figure 1. Scatter plot of pre-ultrafiltration CUS score NYHA classes.
*Statistically significant, NYHA: New York Heart Association, CUS: Chest ultrasound.

Table 8. New York Heart Association classes and their correlation.

Parameter	Pre-ultrafiltration NYHA		Post-ultrafiltration NYHA	
	r	***P***	***r***	***P***
Pre-ultrafiltration IVCCI	−0.025	0.880		
Post-ultrafiltration IVCCI			−0.056	0.740
Pre-ultrafiltration CUS score	0.982	<0.001		
Post-ultrafiltration CUS score			0.927	<0.001

NYHA: New York Heart Association, IVCCI: Inferior vena cava collapsibility index, CUS: Chest ultrasound.

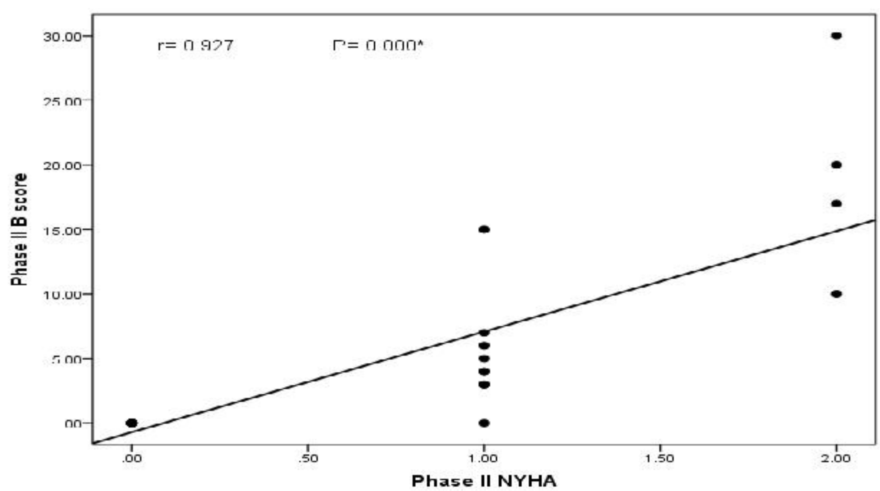

Figure 2. Scatter plot of post-ultrafiltration CUS score NYHA classes.
*Statistically significant, NYHA: New York Heart Association, CUS: Chest ultrasound.

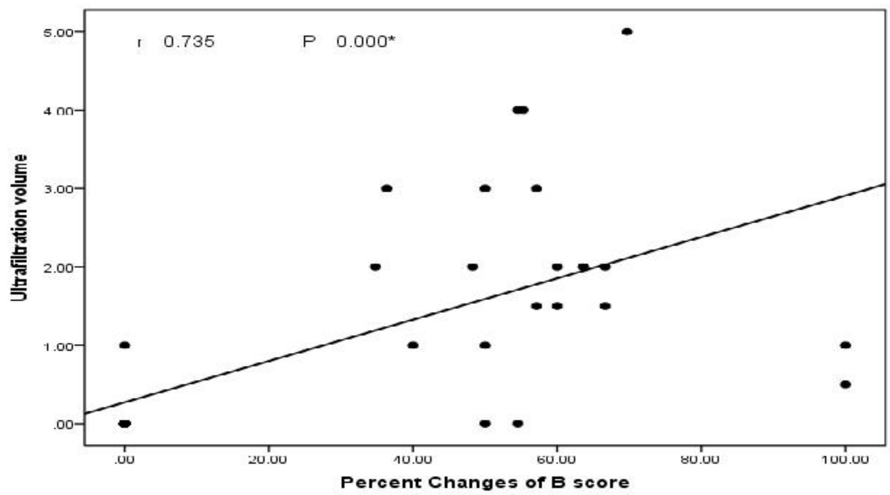

Figure 3. Scatter plot of percent changes CUS score and ultrafiltration volume.
*Statistically significant, CUS: Chest ultrasound.

part of its etiology, sympathetic system and renin–angiotensin–aldosterone system overactivity and vascular rigidity can be other variables. Raised JVP and pedal edema can be caused by concomitant pulmonary hypertension, which is frequently present in HD patients.

The measurement of IVC diameter was successfully used in ICU for the assessment of VS and fluid responsiveness.[21,22] The IVC diameter is determined by: trans-caval pressure = the internal IVC pressure – the external intra-abdominal pressure (IAP). Ignoring the IAP, a curvilinear positive relationship between CVP and IVC diameter is observed as right ventricular (RV) filling pressure estimates.[23-25] Hence, “IVC is a CVP.”[26]

In the current study, there was neither significant reduction of the IVC diameters nor IVCCI after ultrafiltration, nor was there significant correlation between IVCCI and CUS score, or significant correlation between IVCCI with volume loss by ultrafiltration.

These findings are in agreement with similar studies[18] that signify the limitations of IVC parameters in the assessment of volume status in HD patients. In addition, postoperative studies have shown that CVP neither reflects volume status nor predicts volume responsiveness,[27-29] and there were no significant changes in the IVC size and IVCCI after treatment of heart failure.[30] This can be explained by the rapid vascular refilling of IVC, which may occur 1–2 h after ultrafiltration which can restore the pre-ultrafiltration IVC diameter and misguide VS assessment.[31]

CUS score is a well-established tool for the measurement of EVLW in patients with cardiac failure[11,12] and is significantly correlated with EVLW determined by the PiCCO System and pulmonary capillary wedge pressure (PCWP). Furthermore, CUS has also been extensively validated in patients on intensive care.[32]

In the current study, there was a significant correlation between percentage changes of CUS score and volume loss by ultrafiltration. These results are consistent with studies, which found a significant correlation between weight loss and reduction in the number of B-lines[33] and a real-time decrease in B lines as volume is removed.[34]

The ability of CUS to detect rapid EVLW changes after ultrafiltration and the lack of this ability in clinical signs as well as in IVC indices signifies its superiority over these assessment tools and the usefulness of CUS in VS management.

Furthermore, the current study showed a significant correlation between CUS score and NYHA classes in both pre- and post-ultrafiltration states, which signifies the ability of CUS to detect rapid volume changes after ultrafiltration.

Conclusion

CUS can be used to guide management of volume status in HD patients. Neither clinical signs nor IVC indices could reliably indicate VS in HD patients. The CUS score correlated with only NYHA class in the clinical assessments but not with the signs and symptoms of systemic congestion, which may signify its shortage as a stand-alone tool for VS management and the need for concomitant use of other method as BIA.

Study Limitations and Recommendations

Limitations of our study included (1) the present study was a single-center, nonoutcome-based study. Therefore, we suggest a multicentric study with a larger number of patients to validate our results and (2) in HD patients, the increase in EVLW can be related to total body extracellular volume overload or to cardiac dysfunction. Hence, CUS can only estimate pulmonary congestion but not systemic congestion. Therefore, it cannot differentiate euvolemic patients from a patient with systemic congestion, but without lung congestion. We recommend dry weight assessment by combined CUS and BIA to diagnose overhydrated, dry, and very dry HD patients.

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