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Diagnostic Utility of Thoracic Ultrasound in Assessment of Volume Status of Haemodialysis Patients

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ABSTRACT

Background: Optimizing volume status of hemodialysis patients is an important clinical challenge because volume expansion is a critical deadly complication of chronic kidney disease. The use of thoracic ultrasound to detect cases of volume overload and depletion has gained great attention by several studies that are because of its advantage as a rapid, available, non-invasive and free of radiation imaging method.

Aim: To evaluate the usefulness of thoracic ultrasound for the assessment of extravascular lung water and intravascular volume in hemodialysis patients.

Patients and Methods: This prospective observational study was conducted on 30 patients on regular hemodialysis. Assessment of extravascular lung water (EVLW) by number of B –lines, and intravascular volume by measurement of inferior vena cava (IVC) diameter and collapsibility index, was done pre- and post-dialysis.

Results: There was statistically highly significant reduction in number of B-lines and highly significant decrease of IVC minimum and maximum diameters post-dialysis (P value < 0.001). There was also highly significant increase in IVC collapse index following hemodialysis (P value < 0.001).

Conclusion: Lung ultrasound is a useful method for the assessment of both EVLW and intravascular volume. EVLW as represented by B-lines number was highly significantly reduced post-hemodialysis. Intravascular volume assessed by IVC ultrasound was improved by 53% following hemodialysis.

Keywords: Volume status, B-lines, IVC diameter.

INTRODUCTION

Chronic kidney disease (CKD) is defined as kidney damage or a glomerular filtration rate (GFR) of less than 60 ml/min/1.73 m^2 for more than three months. CKD is a term that refers to any degree of renal dysfunction, whether mild, moderate, or severe **(1)**. Dialysis and chronic kidney disease can influence a variety of bodily systems, including the cardiovascular, respiratory, and musculoskeletal systems **(2)**.

Pulmonary complications that have been reported in CKD patients include pulmonary edema, pleural effusion, pulmonary hypertension, respiratory infections, pulmonary fibrosis and hypoxemia **(3)**.

Fluid overflow is a frequent consequence of kidney illness in patients on hemodialysis with end-stage renal disease (ESRD). Fluid overload is difficult to identify since standard clinical indicators are sometimes subjective or difficult to interpret in the presence of kidney disease **(4)**.

The use of lung ultrasound to evaluate fluid status in haemodialysis patients is a straightforward, noninvasive, readily available, and cheap technique. It can determine the amount of EVLW by determining the number of B-lines and the distance between them **(5)**.

The presence of three or more B-lines in a longitudinal plane between two ribs defines a positive area, and the presence of two or more positive regions bilaterally defines a positive exam **(6)**.

PATIENTS AND METHODS

This was a prospective observational study that included 30 patients from Al-Zahraa University Hospital through the period from January 2018 to August 2018. Patients were maintained on regular hemodialysis three times per week, four hours per setting with standard bicarbonate dialysis by using semisynthetic membranes.

Inclusion criteria:

Patients with end stage renal disease on regular dialysis more than 18 years old were included.

Exclusion criteria:

Patients with all causes of alveolo-interstitial syndrome either acute or chronic conditions such as congestive heart failure, Acute Respiratory.

Distress Syndrome (ARDS) and lung fibrosis, even if they are on regular hemodialysis, were excluded from the study as in these conditions B-lines will be present on thoracic ultrasonography but they are not due to volume overload and are not affected by hydration status.

All patients were subjected to the following:

1. Obtaining of a medical history, including co-morbidities, the date of initiation of haemodialysis, and the degree of dyspnea on the modified Medical Research Council scale.

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Table (1): Modified Medical Research Council dyspnea scale [7]

Grade	Description of Breathlessness
Grade 0	Patients show breathless with strenuous exercise.
Grade 1	Patients with shortness of breath when hurrying on level ground or walking up a slight hill.
Grade 2	Patients showing slower walk than other people of the same age on the ground level because of breathlessness, or the need to stop for breath when walking at their own pace on the level.
Grade 3	Patients stop walking for breath after walking about 100 yards or after a few minutes on level ground.
Grade 4	Patients are too breathless to leave the house or breathless when dressing.

2. Clinical examination for body weight before and after dialysis, and signs of hypervolemia as congested neck veins, lower limb edema, and fine basal crepitation.
3. Routine laboratory investigations that included complete blood count, renal function test (serum urea and creatinine), serum sodium, potassium, calcium, phosphorus.
4. Creatinine clearance (CC) was calculated by using Cockcroft and Gault equation:

$$\text{CC in men} = \frac{(140 - \text{age}) \text{ x ideal weight}}{0.814 \text{ x [serum creatinine]}}$$

   in women = 0.85 x creatinine clearance in men [8].
5. Echocardiography to assess cardiac function.
6. Radiological examination including transthoracic ultrasonography for evaluation of EVLW. IVC diameter and collapse index (IVCCI).

Examination steps:

- Ultrasound scanner used was Sonoscape SSI6000, equipped with a 3.5 MHz curvilinear and 8 MHz linear probes, Nanshan, China. Examination by ultrasound was done before dialysis session and was repeated after the session by one hour.

Assessment of EVLW:

1. The patient is placed in a supine or near supine position with the anterior chest wall exposed; 3.5 MHz curvilinear probe was used.
2. The anterior lateral chest was examined on a total of 28 scan sites on the right and left half of the chest, second through fourth (on the right side to the fifth) along the sternum, mid-clavicular, anterior axillary, and mid-axillary lines [9].
3. The total number of B-lines was estimated by counting the number of well-defined, vertical, hyperechoic, dynamic lines beginning from the pleural line and spreading like a laser ray up to the edge of the screen each scan.
4. The lung comet score was divided into three severity levels: "mild" with less than 15 comets, "moderate" with 15-30 comets, and "severe" with more than 30 comets [10].

For evaluation of intravascular volume:

1. IVC was imaged in Sub-xyphoid transabdominal long axis (LA).
2. Patient is placed in supine position.
3. By using m-mode, curvilinear probe was placed just below xiphisternum slightly to the right of midline with the mark dot directed to the patient's head.
4. The IVC diameter was measured from the inner edge to the inner edge of the vascular wall (leading edge method) in the hepatic vein-IVC junction, about 3–4 cm from the confluence of the IVC and right atrium [11].
5. This measurement site was chosen because IVC collapsibility at the intrahepatic section was unaffected by muscular diaphragm activity, but collapsibility at the IVC-right atrial junction [11].
6. The maximum IVC diameter (IVCdmax) was measured as the maximum anterior-posterior dimension at end-expiration.
7. The minimum IVC diameter was measured at end-inspiration (IVCdmin).
8. The IVC collapsibility index was the difference between the maximum and minimum IVC diameters divided by the maximum IVC diameter, expressed as a percentage ([IVCdmax – IVCdmin] / IVCdmax × 100%) [12].
9. Volume status was assessed by using value of IVC collapsibility index: Normally IVC collapses by more than 50% with normal breathing or sniffing. A cutoff value of IVC collapsibility index less than 20% indicates probable hypervolemia [13]. Also IVC collapsibility less than 50% with IVC maximal diameter equals 2.1 cm or more indicates hypervolemia [14]. A cutoff value of IVC collapsibility index more than 50% without a sniff or Valsalva with IVC maximal diameter less than 1.2 cm indicates probable hypovolemia [15].

Ethical approval:

The Ethics Committee of the Faculty of Medicine for Girls, Al-Azhar University approved the study protocol and all patients gave a written consent for participation in this study. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical analysis

Data were collected, revised, coded and entered to the International Business Machines Statistical Package for Social Science (IBM SPSS) version 23. The quantitative data were presented as either means ± standard deviations, ranges, median or interquartile range (IQR) when their distribution found parametric. Qualitative data were presented as numbers and percentages. The comparison between two independent groups was done by using student t-test. Chi-square test was used to indicate strength or direction of the relationship. Pearson correlation co- efficient (r) was used to find out a correlation between 2 parameters where (r) value will be either > 0 (positive correlation), 0 (no correlation) or < 0 (negative correlation). P value ≤ 0.05 was considered significant.

RESULTS

30 patients on regular haemodialysis in Al-Zahraa University Hospital were included in this study.

Table (2): Demographic data of studied group

Criteria		Mean ± SD; No. (%)
Age (year)	Range (22 – 73)	53.00 ± 13.94
Sex	Male	18 (60.0%)
	Female	12 (40.0%)
Comorbidities 29(96.7%)		
	Hypertension	23 (76.7%)
	Ischemic heart disease	13 (43.3%)
	Diabetes mellitus	8 (26.7%)
	Familial Mediterranean fever	1 (3.3%)
Other predisposing factors 4(13%)		
	Polycystic kidney disease	3(10%)
	Analgesic nephropathy	1(3.3%)

Table (2) showed that the mean age of studied patients was 53.00 ± 13.94 ranging from 22 to 73 years. There was male predominance (60%), and about 29 (96.7%) patients had comorbidities, hypertension was the highest recorded followed by ischemic heart disease and diabetes mellitus. Only one patient had familial Mediterranean fever. Other predisposing factors were reported in 4(13%) of patients, 3 patients had polycystic kidney disease and one patient had analgesic nephropathy.

Table (3): Laboratory investigations of studied group

Laboratory investigations	Mean ± SD
HGB (g / dl)	10.70 ± 1.77
WBCs ($\times 10^3/mm^3$)	6.02 ± 1.98
Platelets ($\times 10^3/mm^3$)	197.39 ± 43.35
Urea (mg/dl)	114.97 ± 27.92
Creatinine (mg/dl)	9.04 ± 2.76
Sodium (mEq/L)	132.23 ± 4.24
Potassium (mEq/L)	5.53 ± 1.05
Calcium (mg/dl)	8.68 ± 0.83
Phosphorus (mg/dl)	5.23 ± 1.83
Creatinine clearance (ml\min)	8.64 ± 2.29

Table (3) showed that the Mean ± SD of Hb, WBCs and platelets was (10.70 ± 1.77, 6.02 ± 1.98 and 197.39 ± 43.35) respectively, also this table showed that Mean ± SD of urea, creatinine, sodium, potassium, calcium, phosphorous and creatinine clearance was (114.97 ± 27.92, 9.04 ± 2.76, 132.23 ± 4.24, 5.53 ± 1.05, 8.68 ± 0.83, 5.23 ± 1.83 and 8.64 ± 2.29) respectively.

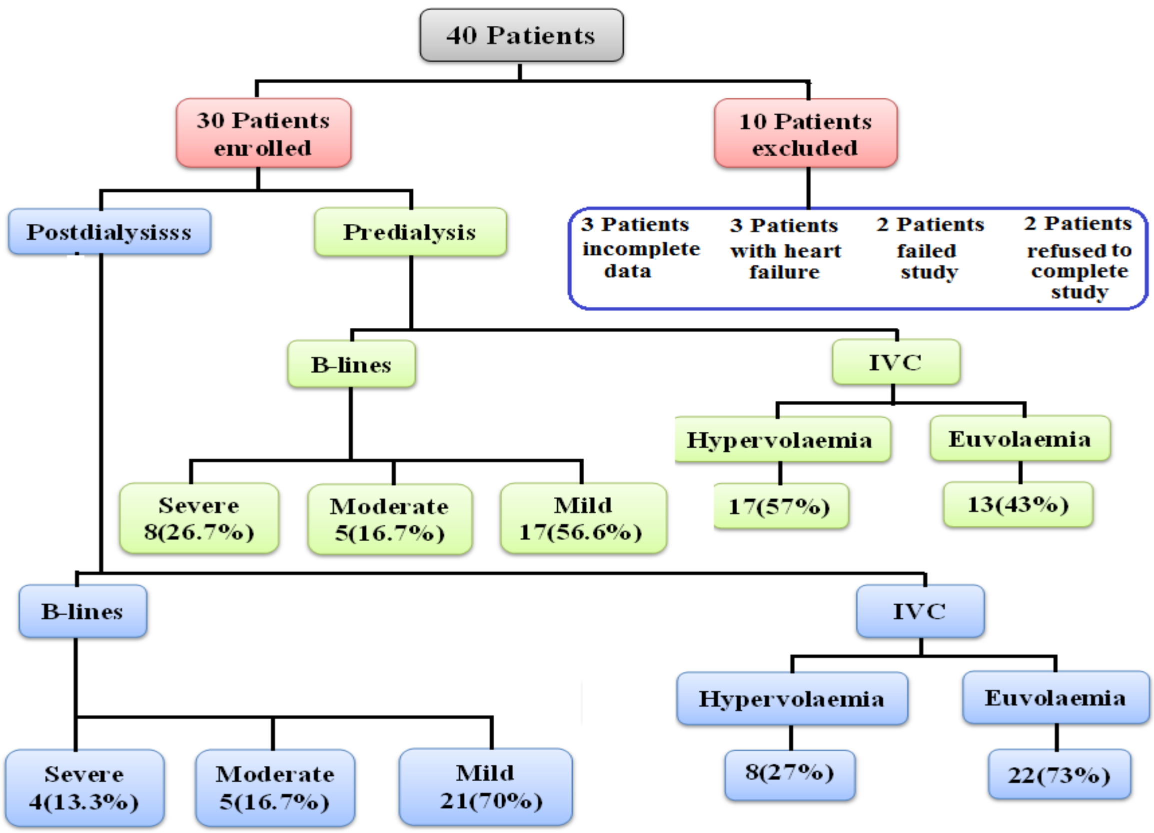

Figure (1): Flow chart of the study

Table (4): Comparison between dyspnea grade according to mMRC dyspnea scale in patients before and after hemodialysis

Dyspnea grade	Before dialysis no. (%)	After dialysis no. (%)	Test value	P-value	Sig.
0	0 (0.0%)	5 (16.7%)	15.818	0.001	HS
1	6 (20.0%)	11 (36.7%)			
2	12 (40.0%)	13 (43.3%)			
3	12 (40.0%)	1 (3.3%)			
4	0 (0.0%)	0 (0.0%)			

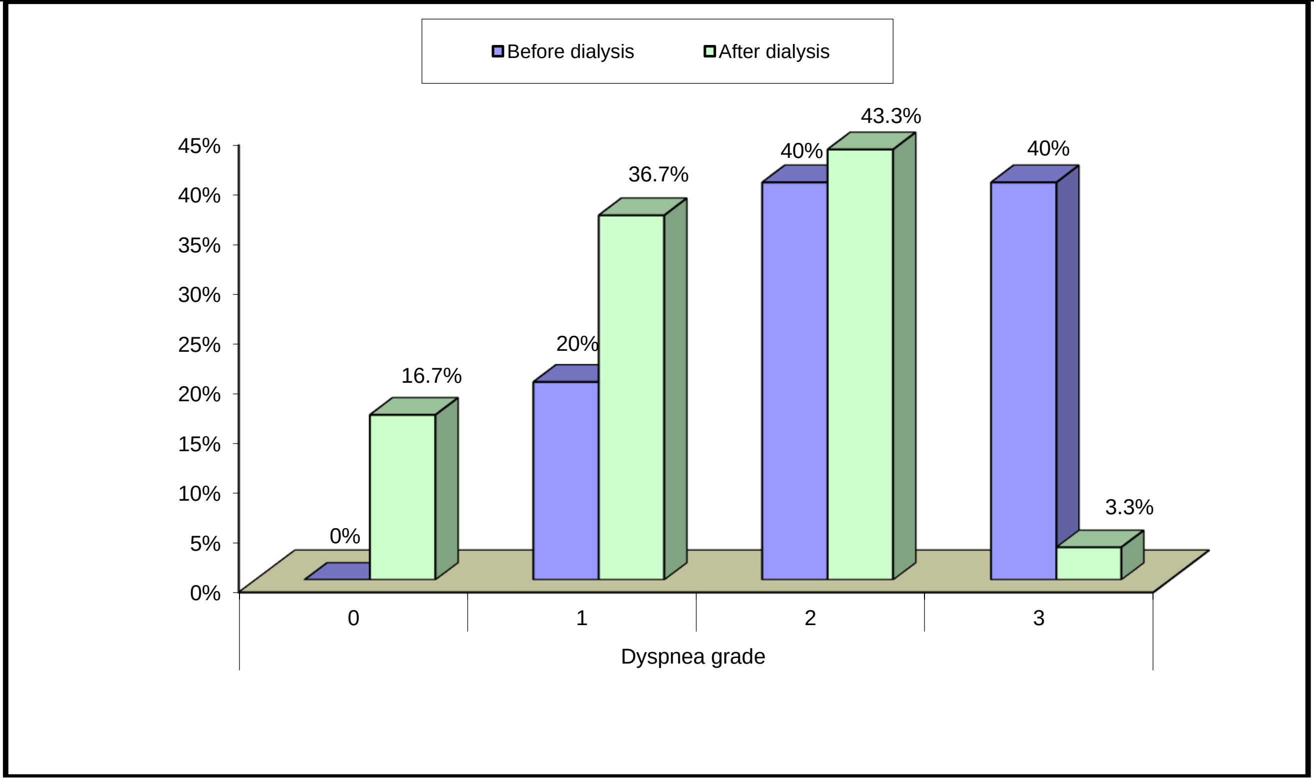

Figure (2): Grading of dyspnea according to modified Medical Research Council (mMRC) dyspnea scale in patients before and after hemodialysis.

Table (4) and figure (2) showed highly significant improvement of dyspnea grade after hemodialysis, most patients had dyspnea grade 2 and 3 before hemodialysis, while after hemodialysis dyspnea grade 0 and 1 were recorded in most studied patients. There were no reported cases with dyspnea grade 4 pre or post-dialysis.

Table (5): Comparison between B-lines before and after dialysis in 28 space scanning method

28 space scanning		B lines Pre dialysis	B lines Post dialysis	Test value	P-value	Sig.
B-lines number	Median (IQR)	13 (9-33)	5 (3 – 16)	-4.786	0.000	HS
	Range	4 – 174	3 – 79			
Distribution of patients according to the degree of pulmonary congestion	Mild	17(56.6%)	21(70%)	9.220	0.027	S
	Moderate	5 (16.7%)	5(16.7%)			
	Severe	8 (26.7%)	4(13.3%)			

IQR: Interquartile range

Table (5) showed the results of 28 space scanning method, before dialysis B-lines number ranged between 4 – 174 with highly significant reduction to 3 – 79 post-dialysis. There was significant increase in number of patients with mild degree of pulmonary congestion and significant decrease in number of patients with severe degree of pulmonary congestion post-dialysis.

Table (6): Comparison between IVC parameters pre and post-dialysis

		IVC measurements		Test value	P-value	Sig.
		Pre dialysis	Post dialysis			
IVC Diameter (cm) min.	Mean ± SD	1.33±0.36	1.05±0.35	10.359	0	HS
IVC Diameter (cm) max.	Mean ± SD	2.07 ± 0.48	1.75 ± 0.49	8.054	0	HS
CI (%)	Mean ± SD	35.60 ± 11.63	40.08 ± 12.46	-6.379	0	HS
CI classifications according to volume status	More than 50 and IVC diameter less than 1.2 cm	4 (13.3%)	7 (23.3%)	6.017	0.59	NS
	More than 50 with spontaneous collapse and IVC diameter less than 1.2 cm	No reported cases	No reported cases			
	Less than 20	4 (13.3%)	3 (10.0%)			
	More than 20 and less than 50, IVC diameter less than 2.1 cm	9 (30%)	15 (50%)			
	More than 20 and less than 50, IVC diameter more than 2.1 cm	13(43.4%)	5(16.7%)			
Volume status	Hypervolemia	17 (57%)	8(27%)	4.444	0.035	S
	Euvolemia	13(43%)	22(73%)			
Percentage of cases improved	53%					

Table (6) showed highly significant decrease of IVC minimum and maximum diameters and highly significant increase in IVC collapse index post-dialysis. We did not report cases of volume depletion pre- or post-dialysis, while about 57% of patients had evidence of volume overload pre-dialysis or post-dialysis. This percentage was reduced to 27%.

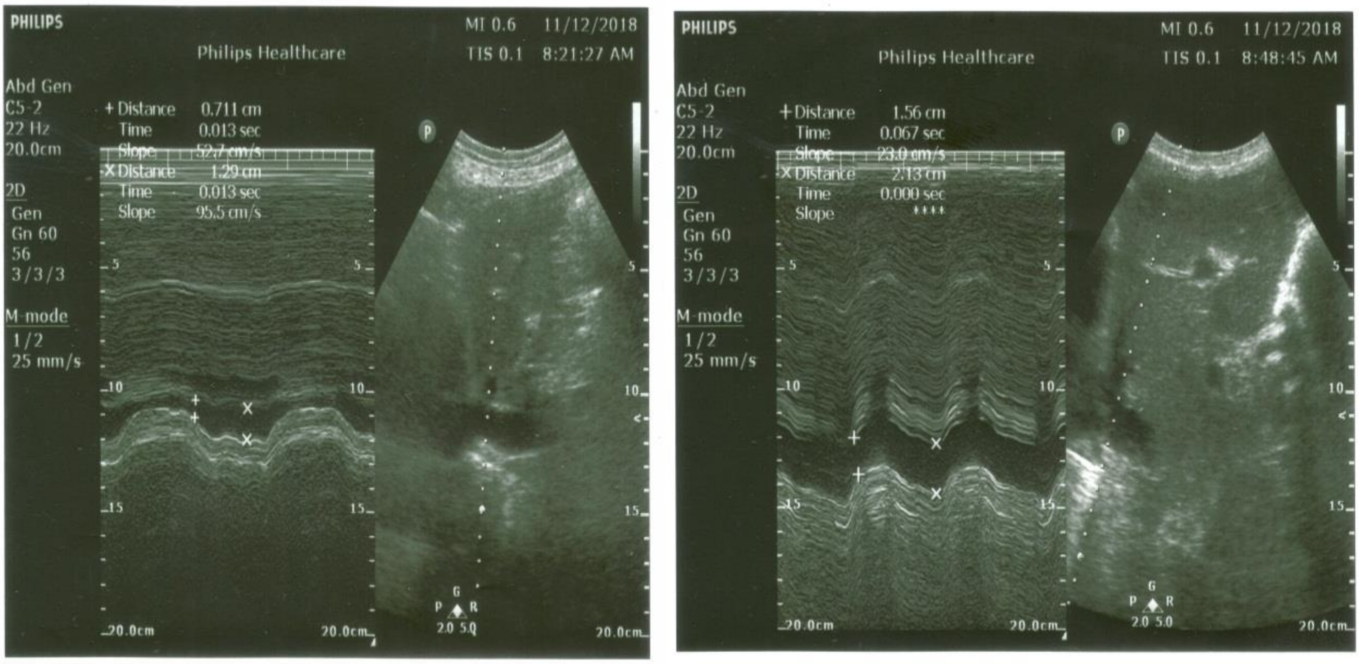

Figure (3): Measurement of IVC minimum and maximum diameters at IVC – hepatic vein junction. (A): Collapsible IVC (B): Non collapsible IVC.

DISCUSSION

Volume expansion is the most prevalent and influential complication of ESRD patients who are maintained on dialysis. It can be clinically apparent or occult, and in both conditions, it is the most powerful determinant of prognosis, complications and mortality of ESRD [(16)]. Assessment of volume status in ESRD patients to achieve euvolaemic status is a challenging target. For this purpose, many novel techniques are employed. Lung ultrasound is a non-invasive, free from radiation, easy and available technique offered for volume status assessment in ESRD patients [(16)].

This study aimed to evaluate the usefulness of thoracic ultrasound for assessment of extravascular lung water and intravascular volume in hemodialysis patients.

Lung ultrasound enables the evaluation of extravascular lung water by identifying B-lines. Such finding not only can quantitatively and qualitatively evaluate extravascular lung water, but it can also assess the effectiveness of hemodialysis by clearance of B-lines indicating fluid removal following hemodialysis sessions [(17)]. Several methods were used to assess B-lines in different ways, we used 28 space scanning technique described by **Gargani and Volpicelli** [(9)].

We reported in current study highly significant improvement of mMRC dyspnea grade post-dialysis, before dialysis (12; 40%) of patients had dyspnea grade 3 while post-dialysis only (1; 3.3%) patient had dyspnea grade 3.

The results of current study showed that lung comets score before dialysis ranged between 4 – 174 with a median (IQR) of 13 (9 –33) while the lung comets score after dialysis for whole patients ranged between 3 – 79 with a median (IQR) of 5 (3 – 16). Before dialysis most patients (17; 56.6%) had mild pulmonary congestion and this percent increased to (21; 70%) post-dialysis. In addition; there was significant reduction in number of patients with severe pulmonary congestion before dialysis (8; 26.7%) to (4; 13.3%) post-dialysis. This is in agreement with the study conducted by **Yousef *et al.*** [(18)] who assessed volume status in 40 chronic renal failure patients on regular haemodialysis by using lung ultrasound and bioempedance analysis in which 42.5% had mild lung comet score pre-dialysis and 55% of patients had mild lung comet score post-dialysis. In contrast to lung ultrasound that is unable to provide information on the total-body volume status as it focuses on pulmonary fluid overload, IVC diameters and CI can evaluate total body volume status, also they can detect cases of post-dialysis volume depletion [(19)].

In current study, ultrasound measurement of IVC diameter and its respiratory variability revealed that mean IVC minimal diameter was 1.33 ± 0.36 cm pre-dialysis and 1.05 ± 0.35 cm post-dialysis, mean IVC maximal diameter was 2.07 ± 0.48 cm pre-dialysis and 1.75 ± 0.49 cm post-dialysis, with highly significant reduction in IVC minimal and maximal diameters post-dialysis. It also revealed highly significant increase in IVC collapse index following dialysis from 35.60 ± 11.63 to 40.08 ± 12.46. The same results were reported by **Trezzi *et al.*** [(20)] who studied the assessment of rapid extravascular water variations in 41 haemodialysis patients, in which mean IVC minimal diameter was 1.05 ± 0.57 cm pre-dialysis and 0.76 ± 0.53 cm post-dialysis. Mean IVC maximal diameter was 1.66 ± 0.38 cm pre-dialysis and 1.19 ± 0.46 cm post-dialysis and IVC collapse index pre-dialysis was 37.60 ± 23.4 and was 42.1± 28.8 post-dialysis, but there was non-significant improvement of collapse index post-dialysis. The explanation is that only heart failure patients with New York heart association (NYHA) dyspnea class IV were excluded from the study.

Limitations of the study:

- Lack of gold standard in current study retarded valuable assessment of sensitivity and specificity of thoracic ultrasound as an imaging method for evaluation of volume status.
- Small number of studied population, as larger number of patients may reveal more significant results.
- Inferior vena cava ultrasound is affected by the rate of ultrafiltration, rapid ultrafiltration could shrink the measured volumes leading to false state of normovolaemia.
- Inferior vena cava ultrasonographic findings are highly conductor dependent and may change according to the axis of collapse.

CONCLUSIONS

- Lung ultrasound is a useful method for detection of both excess extravascular lung water and intravascular volume overload.
- Nephrologists should not rely on clinical evaluation of volume status of ESRD patients as it is helpful but not conclusive in assessment of volume status.
- Current study concluded that there was significant improvement in the degree of pulmonary congestion post-dialysis as B-lines clearance denoted fluid removal by hemodialysis. Also, about 57% of patients had evidence of intravascular volume overload by IVC ultrasound before hemodialysis, this percentage was reduced to 27% following hemodialysis, with 53% improvement.

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