Lung ultrasound and bioimpedance in assessment of volume status of hemodialysis patients

Ghada Youssef[a], Bahaa Zayed[b], Mohammed Momtaz[b], Amin Roshdy[b], Mohamed Shaaban[b]

[a]Cardiology Department, [b]Nephrology Department, Cairo University, Cairo, Egypt

Correspondence to Ghada Youssef, MD, Cairo University Hospital, Kasr Al Ainy St., 17611, Egypt;
Tel: +20 115 118 8999;
e-mail: ghadayoussef@kasralainy.edu.eg

Received 23 June 2016
Accepted 18 October 2016

Kasr Al Ainy Medical Journal
2017, 23:18–23

Background
Assessment of volume status is crucial in patients with chronic renal failure who are maintained on regular hemodialysis.
Aim of the work
The aim of the study was to evaluate the effectiveness of lung ultrasound in detecting changes in volume status in chronic hemodialysis patients and compare it with the gold standard bioimpedance technique.
Patients and methods
Forty chronic renal failure patients on regular hemodialysis (three times per week) since at least 6 months were subjected to full history taking and physical examination, full anthropometric measurements, routine laboratory studies, and conventional transthoracic echocardiography. Lung comet score was assessed in both lungs using lung ultrasound, and total body water (TBW) and TBW% were assessed using bioelectrical impedance. The last two investigations were carried out both before and after a midweek dialysis session.
Results
Most of the patients were male (57.5%) and hypertensive (75%). The mean age was 49.40±16.06 years. The mean lung comet score before and after dialysis was 20.1±15.8 and 14.6±11.8, respectively ($P<0.001$) and the mean TBW was 37.2±9.1 and 35.8±8.5 l, respectively ($P=0.002$). Before dialysis, the lung comet score showed significant correlation with TBW% ($P=0.01$), left ventricular end-diastolic ($P=0.02$) and end-systolic ($P<0.001$) dimensions and significant negative correlation with left ventricular ejection fraction ($P=0.003$). After dialysis, the lung comet score showed only significant negative correlation with left ventricular ejection fraction ($P<0.001$). There was no significant correlation between change in lung comet score (before and after dialysis) and change in TBW% ($P=0.93$).
Conclusion
Bioimpedance and ultrasound lung comet score may provide different but complementary information. Whereas bioimpedance may be more specific to hydration state, lung ultrasound may indicate cardiac condition coexisting with overhydration. It also gives an idea about the hydration state and the effect of dialysis.

Keywords:
bioimpedance, hemodialysis, lung comet score, lung ultrasound

Kasr Al Ainy Med J 23:18–23

1687-4625

Introduction

Chronic volume expansion, either clinically apparent or occult, is a pervasive complication in patients with end-stage renal disease who are maintained on dialysis. Recent studies documented that fluid accumulation between dialysis is a powerful predictor of death and cardiovascular complications [1].

There has been a quest for methods aimed at estimating body fluid volume and for personalizing fluid removal in end-stage renal disease. Early detection of pulmonary congestion is a fundamental goal for the prevention of congestive heart failure in high-risk patients. Assessing subclinical pulmonary edema can help determine the prognosis of dialysis patients [2].

In recent years, the use of lung ultrasound to detect lung water (LW) has received growing attention. In the presence of excessive LW, the ultrasound (US) beam is reflected by subpleural thickened interlobular septa, a low impedance structure surrounded by air with a high acoustic mismatch. This US reflection generates hyperechoic artifacts between thickened septa and the overlying pleura that are defined as 'lung comets'. Lung comets represent the US equivalent of Kerley B lines in standard chest

 DOI: 10.4103/1687-4625.207188

radiographs. Lung ultrasound is increasingly applied to detect and monitor pulmonary congestion [3].

Bioimpedance analysis (BIA) is a noninvasive method for measuring body composition and estimate total body water (TBW), fat percentage, and muscle mass. Preliminary data suggest that BIA-derived parameters predict clinical outcome in chronic hemodialysis patients. Bioimpedance measurement in hemodialysis patients is suitable for assessing body composition, to study hydration status, and to monitor fluid shifts [4].

Although BIA is very simple and noninvasive, it is not available in most hemodialysis facilities, in contrast to US machines, which are relatively cheaper and easily available.

The aim of this work was to evaluate the effectiveness of lung ultrasound in detecting changes in volume status in chronic hemodialysis patients (before and after hemodialysis) and comparing it with the gold standard bioimpedance technique.

Patients and methods

Patients

This study was conducted as a conjoined research between the Cardiology and the Nephrology Departments. Patients were recruited from the dialysis unit over 8 months. All subjects were outpatients on chronic hemodialysis regimen three times a week. A written informed consent was signed by all patients before imaging.

Inclusion criteria

Patients on chronic hemodialysis for at least 6 months were eligible for inclusion in this study.

Exclusion criteria

(1) History of advanced heart failure (NYHA class III and IV secondary to structural heart disease).
(2) Ischemic cardiomyopathy.
(3) Ejection fraction less than 40% (estimated by a recent transthoracic echocardiography).
(4) Interstitial lung disease.
(5) Having undergone amputations or implantation of cardiac pacemakers or defibrillators.
(6) Experience of acute complications within 3 months before the study – for example, vascular, cardiac, infectious, or bleeding complications.
(7) Refusal to participate.

A total of 40 patients were included in the study. All patients were treated three times weekly with standard dialysis using polysulfone membranes. Bicarbonate dialysis with constant ultrafiltration was performed. The dialysate contained sodium (105 mmol/l), potassium (2 mmol/l), chloride (111.5 mmol/l), calcium (1.75 mmol/l), magnesium (0.5 mmol/l), bicarbonate (34 mmol/l), and acetate (3 mmol/l).

Methods

Written informed consent was taken from all patients.

History

Baseline demographic data were collected, including name, sex, and age.

All participants were thoroughly investigated for their medical history, including presence of diabetes or hypertension, history of previous medical problems, surgical history, previous blood transfusion, and prescribed medications.

Examination

The weight of each participant was measured using a digital scale (both before and after the hemodialysis session while in light clothes and barefoot. The height of each participant was measured and the BMI was calculated as body weight in kilograms divided by height in meters squared (kg/m^2).

Supine blood pressure was measured according to the standard protocol, using a mercury sphygmomanometer, both before and after the index hemodialysis session.

Laboratory testing

Blood samples were obtained from each participant after a fasting period of at least 8 h. Laboratory studies included complete blood count, serum levels of total proteins and albumin, and serum levels of urea, creatinine, sodium, potassium, calcium, phosphorus, and parathormone. Virology including hepatitis B virus surface antigen, hepatitis C virus antibody, and HIV antibody using enzyme-linked immunosorbent assay technique was studied.

Transthoracic echocardiography

Echocardiography was performed using a commercially available machine (Esaote) by a high-volume operator on all patients just before and within 24 h after the hemodialysis session. M-mode, 2D, and Doppler images were taken and measurements were obtained.

Lung ultrasound

Lung ultrasound was performed at the Cardiology Department, Kasr Al-Ainy Hospital, on all patients before and after a midweek hemodialysis session. A standard 2.5 MHz echocardiography probe was used for the detection of lung comets. Examinations were performed in the supine position. Scanning of the anterior and lateral chest was performed on both sides of the chest. A lung comet is visualized as a hyperechogenic vertical stripe, spreading with a narrow origin from the pleural line (at the apex of the sector and extending to the edge of the screen (Fig. 1).

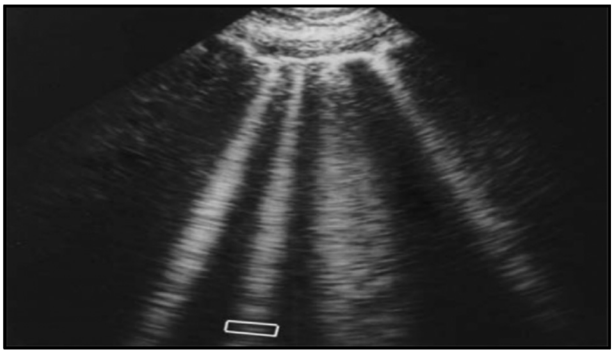
Lung comets (B lines) were calculated in four different planes on both the right and left sides (parasternal, midclavicular, anterior axillary, and midaxillary). On the right side, lung comets were calculated in the second, third, fourth, and fifth intercostal spaces, whereas on the left side lung comets were calculated in the second, third, and fourth spaces only, to make a total of 28 intercostal spaces examined for lung comets. The total number of lung comets was calculated in every intercostal space, ranging from 0 to 10 (full white screen); then sums of each intercostal space were added to calculate the total number of lung comets (comet score). Two different physicians trained in lung ultrasound performed examinations before and after dialysis, with the physician carrying out the postdialysis session blind to predialysis results.

On the basis of comet score, patients were grouped into three categories based on the severity of pulmonary congestion (mild congestion: <14 comets; moderate congestion: ≥ 14 to ≤ 30 comets; and severe congestion: >30 comets).

Bioimpedance analysis

BIA was performed on all patients before and after a midweek hemodialysis session using an analysis machine that uses multiple-frequency whole-body technique. It measures body weight, TBW (l), and TBW%. It also calculates total fat and muscle and bone masses.

Figure 1



Ultrasound image of lung comets (in this image there are four lung comets).

Statistical analysis

Precoded data were entered into the computer using 'Microsoft Office Excel Software' program (2010 for Windows). Data were then transferred to the Statistical Package of Social Science Software program (SPSS-17) to be statistically analyzed. Continuous variables are expressed as mean±SD. Frequency and percentage were calculated for qualitative variables. Comparisons of quantitative variables across groups were made with the *t*-test and those for qualitative ones using the χ^2 or Fisher's exact test. For non-normally distributed variables, the Mann–Whitney *U*-test was performed. The paired-samples *t*-test was used to compare test results before and after hemodialysis. Pearson's correlation coefficients were calculated to signify the association between different quantitative variables. *P*-values less than 0.05 were considered statistically significant.

Results

The present study included 40 patients with a history of chronic hemodialysis since more than 6 months.

Baseline characteristics are described in Table 1 and laboratory data are presented in Table 2.

The mean duration of dialysis session was 3.85±0.4 h and the average volume of fluid filtered was 1575.0±873.7 ml.

The changes in echocardiographic dimensions, lung comet score, and bioimpedance parameters are presented in Table 3.

The change in pulmonary congestion (as judged by the lung comet score) is shown in Fig. 2 and the

Table 1 Baseline characteristics of the studied patients

	n (%)
Sex (male)	23 (57.5)
Diabetes mellitus	16 (40)
Hypertension	30 (75)
	Mean±SD
Age (years)	49.40±16.06
Height (cm)	165.55±7.67
Known dry weight (kg)	68.68±15.38
BMI (kg/m^2)	24.97±4.89
Body surface area (m^2)	1.77±0.22
Duration of CRF (months)	29.80±24.55

CRF, chronic renal failure.

relation between mean lung comet score and degree of mitral regurgitation is shown in Fig. 3.

Before dialysis, there was a positive correlation between lung comets and TBW (r=0.3; P=0.085) and TBW% (r=0.4; P=0.01) and a negative correlation with left ventricular ejection fraction (P=0.003) and duration of chronic renal failure (P=0.02).

After dialysis, there was a strong positive correlation between volume filtered in dialysis and changes in lung comet score (r=0.6; P<0.001) and weight loss after dialysis (r=0.6; P<0.001) and a less powerful positive correlation between volume filtered and TBW (r=0.3; P=0.05).

There was a weak positive correlation between change in lung comets (difference in lung comets after dialysis when compared with before dialysis) and both change in TBW% (difference in TBW% after dialysis when compared with before dialysis) and change in body weight (r=0.095; P=0.56), which were not statistically significant.

Table 2 Laboratory data of the patients before dialysis

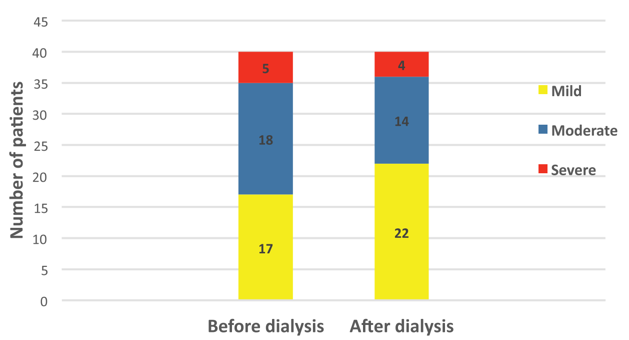
	Mean±SD
Na (mEq/l)	131.6±4.3
K (mEq/l)	4.6±0.6
Creatinine (mg/l)	6.5±2.6
Urea (mg/l)	108.4±53.9
Albumin (mg/l)	2.8±0.3
Hb (g/l)	8.6±0.7
Ca (mg/l)	7.3±0.8
PO_4 (mg/l)	5.2±1.6

Table 3 Comparison of investigational data before and after dialysis

	Before dialysis (mean±SD)	After dialysis (mean±SD)	*P*-value
Body weight (kg)	69.49±15.43	68.58±15.31	<0.001
Systolic blood pressure (mmHg)	142.00±12.90	132.00±8.80	<0.001
Diastolic blood pressure (mmHg)	84.75±6.40	81.00±6.32	0.007
LVEDD (mm)	51.81±5.81	51.60±5.92	0.6
LVESD (mm)	35.26±5.65	34.76±5.83	0.1
EF (%)	59.75±8.29	60.63±7.67	0.1
Lung comets score (no.)	20.10±15.82	14.55±11.81	<0.001
Total body water (l)	37.22±9.15	35.76±8.49	0.002
Total body water (%)	52.70±7.44	52.32±7.09	0.475

EF, ejection fraction; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension.

Figure 2



Distribution of patients according to the degree of pulmonary congestion by ultrasound lung comet score (ULCs before and after dialysis).

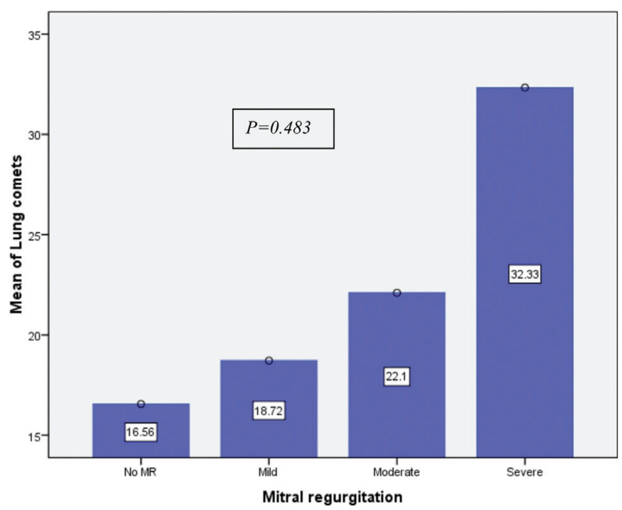
Discussion

The aim of this study was to evaluate the effectiveness of lung ultrasound in detecting changes in volume status in hemodialysis patients and compare it with bioimpedance technique, and to analyze all methods in terms of fluid status variations induced by hemodialysis (HD). The patients in our study were middle-aged with average BMI. Most of them were on long-term hemodialysis (mean=29.8 months).

The average number of lung comets before dialysis in our patients was higher than the average number in the study by Vitturi *et al.* [5], which can be explained by the different hydration state and poorer hemodynamic state in the patients in our study. The presence of lung comets in most of our patients, although often asymptomatic, underlines the capability of lung ultrasound to detect the signs of pulmonary congestion even in a subclinical phase.

The different numbers of lung comets identified in different patients emphasize the importance of

Figure 3



The relation between the severity of mitral regurgitation and the mean lung comet score (before dialysis).

evaluating the relative variation in their numbers before and after dialysis rather than their absolute numbers. Lung comets are movement-dependent and angle-dependent artifacts, which can appear in case of lung fibrosis as well, and attempting to count them precisely can be misleading [6].

As in the study by Vitturi *et al.* [7], our study showed a strongly significant difference in the number of lung comets before and after dialysis ($P<0.001$). Our data confirm that lung ultrasound may recognize rapid changes in pulmonary congestion, supporting its use in monitoring the therapeutic effect of diuretics in patients with pulmonary edema.

The fact that the number of lung comets did decrease during fluid removal, even in asymptomatic patients, suggests that the artifacts seen before HD were due to subclinical fluid overload and not due to static processes such as fibrosis. Lung comets due to nonhydrodynamic processes such as fibrosis of pulmonary septa would not have changed over time.

This study showed no significant correlation between change in lung comets and weight loss after dialysis, in contrast to the findings of Vitturi *et al.* [5], who found significant correlation; however, our findings are supported by those of Mallamaci *et al.* [8]. This may be because changes in lung comets reflect only changes in LW, whereas changes in body weight are better reflected by changes in TBW. Also lung comets are largely dependent on the cardiac condition of the studied patients.

Yet, there was a strong association between volume filtered during dialysis and change in lung comet score and body weight, and this may support the use of lung ultrasound as a cheap, noninvasive and widely available tool to judge the proper volume needed to be removed during dialysis, aiming at the proper dry weight.

Echocardiographic findings in our patients were correlated to lung comets. Our study showed that both before and after dialysis there was a statistically significant negative correlation between lung comets and ejection fraction. Zoccali *et al.* [9] showed similar results. The strong association between these echocardiographic parameters and lung comets suggests that left ventricular disorders play a major role in lung congestion in HD patients [8].

Bioelectrical impedance is a precise and repeatable way for dry weight estimation, which is less prone to interobserver variability compared with clinical estimates. This study showed significant difference between TBW before and after dialysis using BIA ($P=0.002$). Basso *et al.* [10] showed similar results, which further confirms BIA as a reliable technique in detecting fluid variations during dialysis. On the other hand, our study showed no significant correlation between lung comets and TBW both before and after dialysis, but there was significant correlation between lung comets before dialysis and TBW%. Also our study showed no significant correlation between change in lung comets and change in TBW % after dialysis. Paudel *et al.* [11] showed similar results, whereas Basso *et al.* [10] showed significant correlation between the two.

This may be explained by the fact that lung comets are mainly affected by left ventricular condition rather than by hydration state, which is better reflected by BIA. Overhydration can be associated with left ventricular dilatation or failure, and thus lung comet score can also be considered a marker of hydration status, but the correlation is weaker.

One limitation of lung ultrasound in the assessment of hydration state is that lung comet score can provide information only in case of overhydration, whereas bioimpedance spectroscopy can give information in underhydration as well.

Despite this limitation, lung ultrasound remains an easy, harmless, and feasible technique for monitoring the hydration state. Its response to hemodialysis and the cardiac condition should help in decreasing morbidity and mortality in the long term.

We believe that these results in the dialysis population can also be applied to subjects with chronic heart failure. As a matter of fact, this study can be a practical example that lung ultrasound may represent a potential useful tool to monitor the state of congestion in chronic heart failure patients, which is still not accurately measured through the traditional clinical parameters.

Limitations

This study was limited by the following factors: the small number of studied patients; lack of information about the trend of clinical, bioimpedance, and lung ultrasound parameters over a longer time period; lack of data about interdialytic periods; and lack of information about changes occurring in the immediate postdialysis period where re-equilibrium between interstitial and intravascular compartments takes place.

Conclusion

Ultrasound lung comet score and bioimpedance spectroscopy may be complementary, providing different information. Whereas bioimpedance spectroscopy may be more specific to the hydration state, lung ultrasound may indicate a cardiac condition coexisting with overhydration. It also gives an idea about the hydration state and the effect of dialysis. Thus, combining both procedures should decrease morbidity and mortality in hemodialysis patients.

Although bioimpedance technique is the gold standard, the wide availability of US machines makes lung ultrasound the more practical technique to screen HD patients before dialysis sessions to help tailor volume filtration according to each patient's volume status. It also helps to follow up patients between HD sessions to risk-stratify them.

Recommendations

Further studies with a larger number of HD patients are needed for validation of the results of the study.

Interesting fields of further investigation could be the interdialytic period and the immediate postdialytic period where re-equilibrium between the interstitial and intravascular compartments takes place.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Zoccali C, Torino C, Tripepi R, Tripepi G, D'Arrigo G, Postorino M, *et al.* Pulmonary congestion predicts cardiac events and mortality in ESRD. J Am Soc Nephrol 2013; 10:1681–1682.

2 Zadeh K, Regidor D, Kovesdy C, Van Wyck D, Bunnapradist S, Horwich T, *et al.* Fluid retention associated with cardiovascular mortality in patients undergoing long-term hemodialysis. Circulation 2009; 119: 671–679.

3 Trespalacios F, Taylor A, Agodoa L, Bakris G, Abbott K. Heart failure as a cause for hospitalization in chronic dialysis patients. Am J Kidney Dis 2003; 41:1267–1277.

4 Tattersall J. Bioimpedance analysis in dialysis: state of the art and what we can expect. Blood Purif 2009; 27:70–74.

5 Vitturi N, Simoni F, Soattin M, Maresca L, Dugo M. Lung ultrasound imaging in haemodialysis. Intern Emerg Med 2013; 8:87–88.

6 Soldati G, Copetti R, Sher S. Sonographic interstitial syndrome: the sound of lung water. J Ultrasound Med 2009; 28:163–174.

7 Vitturi N, Dugo M, Soattin M, Simoni F, Maresca L, Zagatti R, *et al.* Lung ultrasound during hemodialysis: the role in the assessment of volume status. Int Urol Nephrol 2014; 46:169–174.

8 Mallamaci F, Benedetto F, Tripepi R, Rastelli S, Castellino P, Tripepi G, *et al.* Detection of pulmonary congestion by chest ultrasound in dialysis patients. JACC Cardiovasc Imaging 2010; 3: 586–594.

9 Zoccali C, Tripepi R, Torino C, Bellantoni M, Tripepi G, Mallamaci F. Lung congestion as a risk factor in end-stage renal disease. Blood Purif 2013; 36:184–191.

10 Basso F, Milan Manani S, Cruz DN, Teixeira C, Brendolan A, Nalesso F *et al.* Comparison and reproducibility of techniques for fluid status assessment in chronic hemodialysis patients. Cardiorenal Med 2013; 3:104–112.

11 Paudel K, Kausik T, Visser A, Ramballi C, Fan SL. Comparing lung ultrasound with bioimpedance spectroscopy for evaluating hydration in peritoneal dialysis patients. Asian Pac Soc Nephrol 2015; 20: 1–5.