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Evaluation of Pulmonary Congestion and Volume Status in Conventional Hemodialysis Patients Using Ultrasonography

Konvansiyonel Hemodiyaliz Hastalarında Pulmoner Konjesyon ve Volüm Durumunun Ultrasonografi ile Değerlendirilmesi

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ABSTRACT

Objective: Fluid overload leads to increased mortality in critically ill patients and patients with end-stage renal disease (ESRD). Recently, sonography has been used for assessing fluid overload. In the present study, it was aimed to compare the relationship between lung ultrasonography (LUS) and inferior vena cava (IVC) measurements with each other and with the amount of ultrafiltration (UF) in the evaluation of fluid burden among patients undergoing hemodialysis (HD) and UF.

Methods: The assessments of the lung and IVC were conducted sonographically both before and after HD three times a week. The lung was evaluated in a total of 12 zones using the LUS scoring system. Inferior vena cava was also examined subcostally, and as well as the collapsibility index, the minimum and maximum diameters of IVC were calculated.

Results: The study was composed of 40 patients. After HD, a decrease was observed in the total LUS score, the anterolateral LUS score, and the diameters of IVC. A weak-to-moderate correlation was found between the reduction in total LUS score and the UF (r= +0.387, p=0.014), as well as the decrease between the anterolateral LUS score and the UF (r=+0.321, p=0.022). However, no correlation was found between the IVC measurements and UF. The average amount of UF was found to be 2410 mL.

Conclusion: This study observed a decrease in LUS scores and IVC measurements post-hemodialysis compared to pre-dialysis values. While LUS scores correlated with UF, no correlation was found with IVC diameters. This suggests that, although effective in assessing fluid overload, IVC measurements may not adequately evaluate rapid reductions in fluid volume. Additionally, examining the total or anterolateral lung regions proves beneficial for assessing pulmonary congestion.

Keywords: Lung ultrasonography, inferior vena cava, hemodialysis, ultrafiltration

ÖZ

Amaç: Kritik hastalarda ve son dönem böbrek yetmezliği (SDBY) olan hastalarda sıvı yüklenmesi mortalitede artışa neden olur. Son zamanlarda sonografi sıvı yüklenmesini değerlendirmek için kullanılır. Bu çalışmada hemodiyaliz (HD) ve ultrafiltrasyon (UF) uygulanan hastalarda sıvı yükünün değerlendirilmesinde akciğer ultrasonografisi (LUS) ve inferior vena kava (İVK) ölçümlerinin birbiriyle ve UF miktarı ile olan ilişkisinin karşılaştırılması amaçlanmıştır.

Yöntem: Haftada üç kez HD ve UF uygulanan SDBY hastaları HD öncesi ve sonrası değerlendirildi. Akciğer toplam 12 alanda LUS skor ile değerlendirildi. İnferior vena kava, subkostal olarak incelendi, maksimum, minimum çapları ve kollapsibilite indeksi hesaplandı.

Bulgular: Çalışmaya 40 hasta dahil edildi. Hastaların HD sonrasında total LUS skorlarında, anterolateral LUS skorlarında ve İVK minimum ve maksimum çap ölçümlerinde azalma gözlendi. Total LUS skorunda azalma ile UF miktarı arasında, anterolateral LUS skoru ile UF arasında sırasıyla düşük-orta düzeyde korelasyon (r=+0,387, p=0,014), (r=+0,321, p=0,022) saptandı. Hemodiyaliz öncesi dönemde total LUS skoru ile İVK maksimum çapı arasında iyi derecede (r= +0,899, p<0,001) korelasyon bulundu. Fakat İVK ölçümleri ile ile UF miktarı arasında korelasyon bulunmadı. Ortalama UF miktarı 2410 mL olarak bulundu.

Sonuç: Bu çalışmada HD öncesine göre, HD sonrasında LUS skoru ve İVK ölçümlerinde azalma gözlenmiştir. LUS skoru UF ile korele iken, İVK çapları ile LUS skoru arasında korelasyon tespit edilmemiştir. Bu bize sıvı yüklenmesi için İVK'nin değerlendirilmesinin faydalı olduğunu fakat hızlı sıvı azalması ile ilgili yetersiz olabileceğini göstermektedir. Ayrıca akciğerin total veya anterolateral bölgelerinin değerlendirilmesinin pulmoner konjesyonun değerlendirilmesinde faydalı olduğunu göstermektedir.

Anahtar sözcükler: Akciğer ultrasonografisi, inferior vena kava, hemodiyaliz, ultrafiltrasyon

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INTRODUCTION

Critically ill patients in intensive care units with conditions such as sepsis, respiratory failure, renal failure, and acute respiratory distress syndrome often exhibit a positive cumulative fluid balance. Independently, a positive fluid balance in critically ill patients is associated with an increased mortality risk (1,2). Therefore, clinicians aim to avoid these adverse outcomes, and at certain stages of the disease, they may require interventions such as diuresis or renal replacement therapies to initiate de-resuscitation (3). During such treatments, efforts are made to ensure that achieving a negative fluid balance does not lead to hypovolemia and hypoperfusion. At all phases of fluid resuscitation, clinical observations, supported by monitoring tools, are of vital importance.

For this purpose, monitoring parameters such as cardiac output and extravascular lung water index (EVLWI) provide critical information about volume status and tissue edema (4). For this purpose, both invasive and minimally invasive methods can be employed. However, recently, non-invasive bedside ultrasonography applications (POCUS) performed by non-radiologist physicians have become the preferred approach. B-lines observed in lung ultrasonography (LUS) are reverberation artifacts reflecting EVLWI (5). B-lines are interpreted as the reflections of the ultrasound beam by thickened subpleural interlobular septa. These comet tail artifacts extending to the end of the screen are considered sonographic indicators of lung interstitial syndrome. On the other hand, it seems that there are similar purposes in end-stage renal disease (ESRD). The accurate determination of volume status and management of fluid accumulation are of the same importance in this patient group as in critically ill patients (6). Patients' clinical evaluation and dry weight are generally used to determine the amount of ultrafiltration (UF) in conventional hemodialysis (HD) patients (7). However, due to the limited diagnostic performance of these methods, nephrologists also resort to noninvasive methods such as POCUS. In many studies, LUS, inferior vena cava (IVC) diameter, and collapsibility index (CI) have been used for this purpose (8–10). Because many components affect pulmonary congestion and volume status in critically ill patients, it is difficult to standardize patients for this purpose. The population of our study was determined to be conventional HD patients, considering that the results we would obtain would guide critically ill patients. In this study, the primary aim was to determine the relationship between LUS and IVC sonographic measurements and UF during conventional HD and UF treatments in patients with ESRD and anuria. The secondary aim was to evaluate the applicability of these methods in assessing the fluid status of these patients.

MATERIAL and METHODS

This study was carried out as an observational prospective study at Necmettin Erbakan University Hospital between March 2021 and 2022 under the principles stated in the Declaration of Helsinki. Approval was obtained from the ethics committee of the faculty (The Turkish Pharmaceutical and Non-Medical Device Research Agency, reg. number 2018/1531, and date: November 26, 2018), and written and verbal consent was also obtained from all patients participating in the study.

Patients and Data Collection

In the study, adult patients diagnosed with ESRD, who had a glomerular filtration rate below 10 mL^{-1} min^{-1} 1.73 m^{-2}, were included and examined. These patients had been receiving standard bicarbonate dialysis and UF using semi-synthetic membranes three times a week for at least six months. Patients received the HD treatments as outpatients and left the hospital at the end of each session. However, the exclusion criteria included individuals with less than 4-hour HD, those not undergoing UF and with a body mass index of 40 or higher, individuals with interstitial lung disease, those classified as class IV heart failure under the functional classification of the New York Heart Association, and those with a heart pacemaker.

The demographic data, dry weight, and medical history of the patients were recorded. The heart rate (HR), mean blood pressure (BP), peripheral arterial oxygen saturation, and the UF volume conducted at the end of HD were recorded both before and after dialysis.

Sonographic Assessment

Before and after HD, sonographic assessments were conducted by the same experienced intensivist. A convex probe (C6-2 MHz) was used for the examination. The lung was divided into anterior, lateral, and posterior regions using the anterior and posterior axillary lines as a guide, and further separated into upper and lower areas. Additionally, the posterolateral alveolar and/or pleural syndrome (PLAPS) point was examined in each hemithorax. The total examination area was 12 fields in both lungs. The B-line and its frequency were evaluated using a modified LUS scoring system (Figure 1,2). The LUS score was calculated (Score 0: A-lines, lung sliding, two or less B-lines, Score 1: Three or more B-lines, Score 2: Multiple coalescences of B-lines, Score 3: Pulmonary consolidation or presence of tissue pattern) (11). The total LUS score was calculated, ranging from a minimum of 0 to a maximum of 36 points. The delta B score was determined by subtracting the pre-dialysis score from the post-dialysis score. Additionally, the pleural effusion was assessed in the posterolateral regions of both lungs.

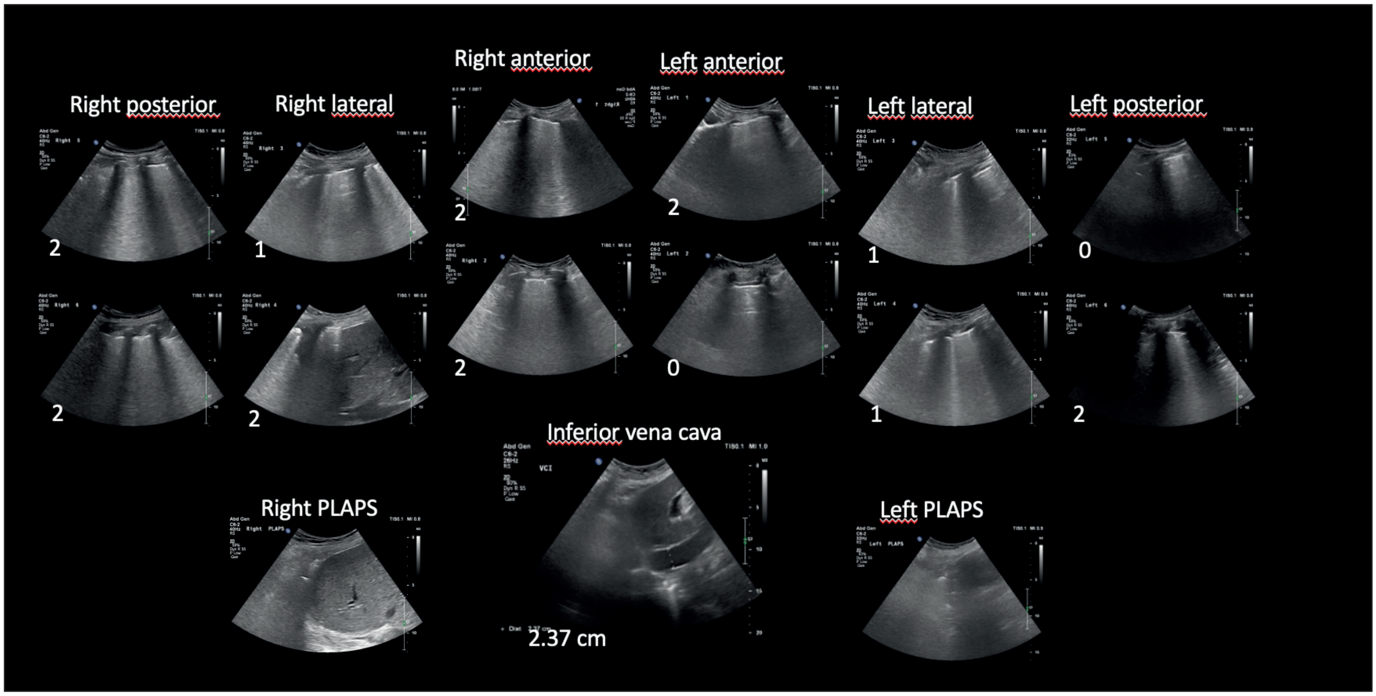

Figure 1: Images from a patient undergoing the examinations of LUS and IVC before HD. The LUS scores are included below each image. The total LUS score before HD was calculated to be 17. The diameter of the IVC was measured at 2.37 cm. **HD:** Hemodialysis, **IVC:** Inferior vena cava, **LUS:** Lung ultrasonography, **PLAPS:** Postero-lateral alveolar and/or pleural syndrome point.

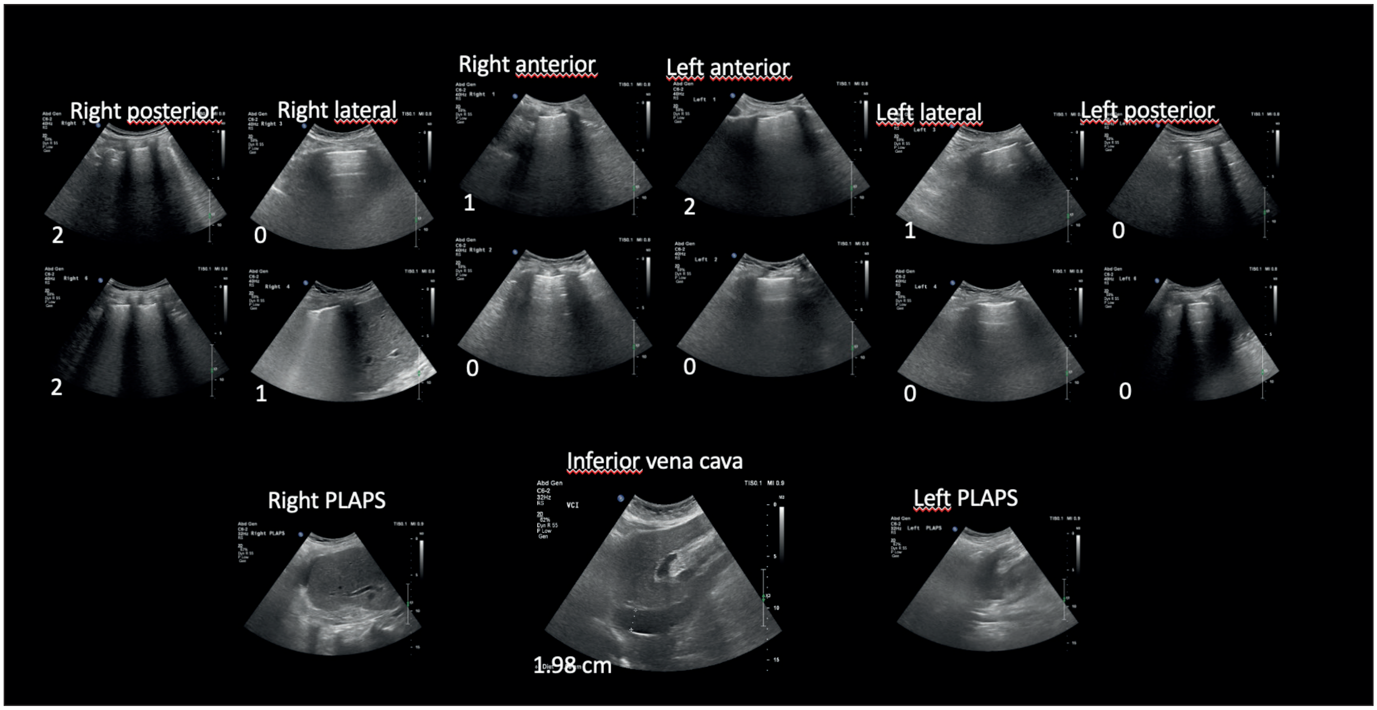

Figure 2: Images showing the investigations of LUS and IVC of the same patient examined after HD. The LUS scores are included below each image. The total LUS score after HD was calculated to be 9. The diameter of IVC was measured at 1.98 cm. **HD:** Hemodialysis, **IVC:** Inferior vena cava, **LUS:** Lung ultrasonography, **PLAPS:** Postero-lateral alveolar and/or pleural syndrome point.

The IVC assessment was conducted with a convex probe from the subxiphoid region, just 2 cm below the cavatrial junction. The dimensions of the IVC's inspiratory (IVC-minimum) and expiratory (IVC-maximum) were measured using M-mode. The collapsibility index (CI) is calculated using the formula IVC-CI = IVC maximum diameter - IVC minimum diameter / IVC-maximum x 100.

In terms of the sample size, a total minimum sample size of 38 was calculated for the comparison of two dependent groups with 90% power, 5% Type 1 error, and an effect size of 0.5.

Statistical Analysis

The research utilized the Statistical Package for the Social Sciences software, version 18.0, for the analyses (SPSS Inc., Chicago, IL, USA). Descriptive analyses were presented as frequency data as count (n) and percentage (%), and numerical data as mean±standard deviation (SD). The suitability of numerical data for a normal distribution was examined using analytical methods (the Kolmogorov-Smirnov and Shapiro-Wilk tests). For numerical variables conforming to a normal distribution, the *t*-test was employed within the dependent groups. The relationship among the normally distributed numerical data was assessed using the Pearson correlation analysis, whereas the Spearman correlation analysis was applied for the data where at least one variable did not follow a normal distribution. The correlation coefficients were interpreted as follows: r = 0.05-0.30 indicated a low correlation; r = 0.30-0.40, a low-to-moderate correlation; r = 0.40-0.60, a moderate correlation; r = 0.60-0.70, a good correlation; r = 0.70-0.75, a perfect correlation; and, r = 0.75-1.00, an excellent correlation. All tests were deemed statistically significant at a p-value of < 0.05 (12).

RESULTS

Forty patients were included in the study. The most common comorbidities were hypertension (HT) and diabetes mellitus (DM) (Table I). Additionally, the conditions leading to ESRD were found to be HT, DM, and having a single kidney. Hemodialysis was administered via a catheter to only 10% of the patients. The remainder received HD via arteriovenous fistulas. The average volume of UF was found to be 2410 mL. After the sessions of HD, there was a significant decrease in patients' average arterial pressure and body weight (p<0.001), and an increase was observed in HR (p=0.039). No severe hypotension requiring medical intervention and causing clinical symptoms was observed. A moderate correlation was found between the amount of UF and the change in body weight (r=0.489, p= 0.018).

The posterior LUS scores remained unchanged before and after HD. It was found that the IVC-CI measurements were similar before and after HD. However, significant changes were found in other sonographic measurements (Table II). A strong correlation was identified between the total LUS score and the maximum diameter of the IVC before HD (r = +0.899, p<0.001). Additionally, a low-moderate correlation was detected between the amount of UF and the change in the total LUS score (r = 0.387, p = 0.014), as well as the change in the anterolateral LUS score (r = 0.321, p=0.022). No correlation was found between the IVC measurements and the amount of UF.

Table I: Demographic Data and Medical History

	n (%), mean ± SD (min-max)
Age (year)	60.27±14.22 (22-85)
Sex (M/F) (%)	25/15 (62.5, 37.5)
Duration of HD (year)	5.17 ± 4.49 (1-22)
Co-morbidity	
Hypertension	29 (72.5)
DM	20 (50)
Hyperlipidemia	3 (7.5)
Other	10 (25)

SD: Standart deviation, **M:** Male, **F:** Female, **DM:** Diabetes mellitus, **HD:** Hemodialysis.

Table II: Sonographic Data and Body Weight (mean ± SD)

	Before HD	After HD	p-value
LUS			
Total LUS score	11.7 ± 4.9	7.57 ± 3.8	**< 0.001***
Anterior	4.45 ± 2.25	2.10 ± 1.61	**<0.001***
Lateral	3.85 ± 1.9	2.37 ± 1.3	**< 0.001***
Posterior	3.47 ± 1.7	3.10 ± 1.9	0.062*
Anterolateral	8.30 ± 3.8	4.47 ± 2.6	**< 0.001***
IVC			
IVC-minimum (cm)	6.8 ± 3.1	5.5 ± 3.1	**< 0.001***
IVC-maximum (cm)	10.0 ± 4.8	8.3 ± 4.8	**< 0.001***
IVC-CI (%)	31.29 ± 4.30	31.64 ± 10.34	0.853*
Body weight (kg)	72.8 ± 14.6	70.5 ± 14.4	**< 0.001***

CI: Collapsibility index, **HD:** Hemodialysis, **IVC:** Inferior vena cava, **LUS:** Lung ultrasonography. ***:** t-test.

DISCUSSION

The present study demonstrated that, in comparison to measures taken before HD, there were decreases in the LUS score and IVC diameters following HD. Decreases in the total LUS score and anterolateral LUS score were correlated with the amount of UF. However, no correlation was found between the IVC diameters and UF. These findings indicate that when evaluating pulmonary congestion, it is not only a comprehensive assessment of lung regions but also the importance of anterolateral assessments. Additionally, while IVC is useful for assessing fluid loading, it may be inadequate for rapidly detecting the decreases in fluid volume.

Extravascular lung water index constitutes a central element of the fluid volume in the body and reflects the fluid content within the pulmonary interstitium, which is affected by the lung permeability and the filling pressure of the left ventricle. B-lines, characterized by vertical hyperechoic reverberation artifacts extending to the edge of the screen, are acknowledged as the sonographic markers of pulmonary interstitial syndrome (13). Many studies have documented a decrease in B-lines during HD treatment, which is associated with the UF volume (7,10,14-17). This decrease is indicative of fluid clearance in the lungs, resulting from the removal of excessive fluid load (10,17). In our study, we assessed B-lines using the LUS score and found that the decrease in the LUS score observed after HD was correlated with the volume of UF. The number of lung fields examined varies across different studies (7,10,14–16,18). While 28 regions of the lung were evaluated in detail in several studies, others examined only four areas of the lung. Our aim here was to assess the lung using a functional approach. In our study, a total of 12 points were evaluated, encompassing the anterior, lateral, and posterior regions of the lung. We found that the amount of UF was correlated with both the total and anterolateral LUS scores. This finding suggests that assessing only the anterolateral region may be sufficient to evaluate pulmonary congestion. Although only a weak correlation was observed, the p-value was statistically significant. In a study evaluating pulmonary congestion in HD patients by comparing LUS with thoracic bioimpedance, a greater reduction in the number of B-lines was noted in the anterolateral regions after HD, compared to the posterior regions (19). The results obtained in our study are similar to those reported by this study. Consequently, we believe that it is important to consider the assessment of the anterolateral area, especially in inpatient groups, such as critically ill patients, where the examination of the posterior areas may be challenging and suboptimal. Numerous studies have evaluated fluid removal in HD patients using the measurements of IVC (10,17). In our study, a correlation was found between the maximum IVC diameter before HD and the LUS score. However, despite significant reductions in both the minimum and maximum IVC diameters following HD, no correlation was found between these measurements and the volume of UF. Although the IVC measurements can provide insights into a patient's fluid status, they are not sufficient for detecting rapid volume changes. These results are consistent with those in other studies investigating the same entity (10,17).

In addition, our study found no correlation between changes in the number of B-lines and IVC measurements. This may have been because the two ultrasound techniques assessed different fluid compartments. The measurements of IVC reflect the degree of intravascular volume, whereas B-lines indicate the level of EVLW in the lung interstitium. After HD, a little time is required for the re-equilibration between the interstitial and intravascular compartments (20).

Patients receiving HD are a well-defined model since they have controlled fluid removal happening quickly and consistently, and they show varying levels of volume overload. During HD, arrhythmias, hypotension, sudden cardiac arrest, and even sudden deaths have been reported due to changes in volume and electrolytes. After HD increases in HR and alterations in the electrocardiography findings have been observed (21). In our patients, an increase in HR and a decrease in BP were observed following HD. However, no serious complications requiring intervention were encountered in any of the patients. In a study, effective and safe management of BP was achieved by using the guidance of LUS for UF (22). In our study, based on the dry weight of the patient, a nephrologist determined the amount of UF. Considering that these complications are a significant source of mortality and morbidity in ESRD, it is expected that UF guided by LUS will increasingly be integrated into clinical practice in the future.

Despite its many known advantages, the limitations of ultrasound include being practitioner-dependent and requiring supervised training for accurate interpretation (23). In our study, the interpretation of images was performed by an intensivist with significant experience in the field. Additionally, while our study included measurements of IVC, the absence of echocardiographic evaluation may be considered a limitation.

CONCLUSION

In the present study, we observed a decrease in both LUS scores and IVC diameters after HD, compared to those performed before the measurements of HD. Both the total LUS and the anterolateral LUS scores were weakly correlated with the volume of UF. We believe that the anterolateral examination should be considered for a quicker and easier assessment of pulmonary congestion in clinical practice. Before HD, the maximum diameter of IVC was correlated with the LUS score. After HD, although a reduction in IVC diameters was noted, no correlation with UF was identified. This suggests that while IVC is useful for assessing fluid loading, it may be inadequate for evaluating rapid fluid removal. Although our study focused on conventional HD patients, we propose the necessity of designing comprehensive studies that include critical patients. In these studies, an integrated approach combining LUS, echocardiography, and the Venous Excess Ultrasound Score should be used to effectively assess congestion and volume status.

AUTHOR CONTRIBUTIONS

Conception or design of the work: FG
Data collection: HE, FG, NYS
Data analysis and interpretation: HE, FG
Drafting the article: FG, HE
Critical revision of the article: FG
Other (study supervision, fundings, materials, etc): FG, HE, NYS
The author (FG, HE, NYS) reviewed the results and approved the final version of the manuscript.

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