Noninvasive Hemodynamic Profiling of Patients Undergoing Hemodialysis Using a Handheld Ultrasound Device

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Abstract

INTRODUCTION: Accurate determination of volume status for patients with end-stage renal disease is essential in determining ultrafiltration rate during hemodialysis (HD). To complement the current dry weight method, inferior vena cava (IVC) collapsibility, made accessible by point-of-care ultrasonography, is considered. This study determined the utility of IVC measurement in estimating the volume status of patients during HD in comparison to clinical parameters.

METHODS: A single-center cross-sectional design including 53 HD patients was conducted, with IVC measurements done through the Butterfly iQ ultrasound (Butterfly Network, Burlington, Massachusetts).

RESULTS: Most patients were hypervolemic before HD based on weight (94.3%) and IVC collapsibility index (IVC-CI; 75.5%), but only 30% had clinical symptoms. Body weight, maximum IVC diameter, minimum IVC diameter, and indexed IVC size significantly decreased after HD, whereas IVC-CI, blood pressure, and heart rate were unchanged. For the subset of patients with symptoms, absolute values of IVC measures were higher, but did not significantly change after HD, unlike in those without symptoms. For volume classification, there are discrepancies in the classifications based on the different measures, with most improvement seen when weight was used, but which was not reflected in IVC-CI. Change in weight and IVC measures were not significantly correlated.

DISCUSSION: This pilot study showed that the current dry weight method provides ultrafiltration rate estimation without causing intradialytic events. However, IVC can be a supplemental parameter to set higher targets and increase volume removal enough to cause intravascular change, especially in symptomatic patients. The incongruencies in classifying volume status suggest that there is no single measure to determine hemodynamic status and that using multiple parameters may provide a more reliable estimate.

KEYWORDS: inferior vena cava measurement, volume status in hemodialysis, point-of-care ultrasonography

INTRODUCTION

Ensuring accurate volume status assessment for patients with end-stage renal disease (ESRD) is critical as they rely on the ultrafiltration (UF) rate set by clinicians during hemodialysis (HD) for fluid homeostasis in lieu of functional kidneys. Currently, clinical symptoms and dry weight, or "the lowest postdialysis weight at which patients are stable with minimal symptoms of hypervolemia and hypovolemia,"[1] is used to set the UF. However, this has its limitations and may be affected by physician subjectivity. Other measures have been investigated: clinical parameters such as blood pressure, heart rate, congestive symptoms, and edema may not be specific and are not always reliable.[1] Static parameters, such as central venous pressure, right atrial pressure, and pulmonary artery occlusion pressure, are more reliable but are invasive. Dynamic parameters such as arterial pressure wave form and inferior vena cava (IVC) collapsibility show promise because these can be used to predict cardiac output response to volume changes. Finding a more accurate measure is important to prevent hypervolemia, which leads to hypertension, left ventricular hypertrophy, heart failure, and pulmonary edema, or hypovolemia, which may cause hypotension, cramps, and chest pain.[2]

Inferior vena cava size and collapsibility are used in echocardiography to estimate right atrial pressure and fluid responsiveness. Studies have also used indexed IVC size (IVC_i) and collapsibility index (IVC-CI) to factor in differences between diameters and body surface area. There are no standardized cutoffs yet, but literature cites hypovolemia as IVC_i of <8 mm/m^2 or IVC-CI of >75%, euvolemia as IVC_i of ≥8 mm/m^2 and ≤11.5 mm/m^2 or IVC-CI of ≥40% and ≤75%, and hypervolemia as IVC_i of >11.5 mm/m^2 or IVC-CI <40%[3]. Use of IVC measures for HD patients has been documented in several studies. Brennan et al[3] showed large discrepancies between weight-based and IVC-based assessment. The relationship between IVC change and weight change is also inconsistent, with one article showing the change in IVC diameter and collapsibility to be correlated with weight change[4] and another showing no significant correlation of IVC collapsibility with weight loss, despite documenting a significant decrease in collapsibility before and after HD, along with other measures of volume assessment.[2]

This study aims to determine the utility of using a handheld ultrasound in estimating the fluid status of patients with ESRD through change in IVC diameter and collapsibility before and after HD. Specifically, the association between IVC diameter and collapsibility before and after HD was evaluated, along with its relationship to symptoms and weight change. Results intend to determine whether IVC measurement can be an additional hemodynamic measure in setting adequate UF rate for patients undergoing outpatient HD.

METHODOLOGY

Population and Sample

Among patients with ESRD undergoing regular outpatient HD, a sample of 53 patients were included in the study. Patients 18 years or older with chronic kidney disease stable enough to tolerate outpatient HD were included. Abdominal pathology that precluded adequate imaging, poor ultrasonographic window, and inability to tolerate the required position for imaging were grounds for exclusion. Patients were sampled nonsystematically, with all who met the inclusion criteria and who consented to participating in the study included.

Methodology

A single-center, observational cross-sectional study was conducted at the outpatient HD unit of a tertiary hospital in December 2021. Informed consent was secured before starting the HD session. Once the patient consented, a short interview along with the initial point-of-care ultrasound (POCUS) was done by two of the investigators using the Butterfly iQ ultrasound (Butterfly Network, Burlington, Massachusetts), a handheld 313-g probe with two-dimensional (2D) array ultrasound-on-chip, 9000 micromachined sensor, and 1- to 10-MHz transducer, connected to an iPad (Apple Inc, Cupertino, California). One investigator performed the ultrasound, and another measured the IVC diameters, for all patients to minimize interobserver variability.

The IVC was visualized with the probe on top of the abdomen in the subxiphoid area. From the subcostal view of the heart, the right atrial IVC junction was traced, and M-mode analysis was done at a fast sweep speed approximately 2 cm from the junction and at a point where IVC borders were most visible. Patients were instructed to sniff, and the M-mode imaging was acquired. The widest IVC diameter and the narrowest IVC diameter were measured. Images were acquired twice or thrice, with the measurements averaged. The process was repeated at the end of the HD session. Using the measurements, IVC-CI, calculated as (maximum inferior vena cava diameter [IVC_{dmax}] – minimum inferior vena cava diameter [IVC_{dmin}]) / IVC_{dmax}] × 100, and IVC_i, obtained by dividing IVC_{dmax} by the body surface area, were calculated before and after HD. Weight before and after HD, vital signs, HD settings, and intradialytic events were obtained through the patients' HD records. The most recent laboratory tests at the time of IVC measurement were obtained from the hospital Laboratory Information System, whereas ejection fraction was obtained from the most recent 2D echocardiography result documented in the Intellispace Cardiovascular application.

All data were recorded on data collection forms and subsequently encoded. Patients were assigned unique identification numbers to protect confidentiality. Inferior vena cava measurements were not disclosed to patients or the nephrologists to avoid influencing the UF rate that was set.

Approval for this study was obtained from the hospital's institutional review board. All procedures were performed in accordance with ethical and regulatory guidelines. Informed consent was secured before data collection.

Statistical analysis
Data were encoded in an electronic spreadsheet file and analyzed using Stata release 13 (StataCorp LP, College Station, Texas). The continuous variables are presented as mean, standard deviation, and range, whereas the qualitative variables as frequency and percentage. The comparison of parameters was determined using a series of paired *t* test for continuous variables, and χ^2 test for categorical variables, especially before and after HD. Pearson correlation coefficients were computed for the change in dry weight against IVC measurements, specifically IVC_{dmax}, IVC_{dmin}, IVC_i, and IVC-CI. All tests were performed using two-tailed levels of statistical significance set at $P < 0.05$

RESULTS

Baseline clinical characteristics of the patients included in the study are listed in Tables 1A and 1B. The mean age of the sample was 58 years, with slightly more female (52.83%) than male patients (47.17%). Most undergo HD thrice a week (92.45%). Almost all patients were hypertensive (90.57%), and more than half had diabetes mellitus (56.6%). In terms of cardiac medications, the most common were β-blockers (71.7%) and calcium-channel blockers (71.7%). Approximately only half of the patients were on statins (52.83%). Most patients did not have symptoms at the start of the HD session. Among those who did, the most frequent were pedal edema (24.53%) and dyspnea/shortness of breath (16.98%).

The comparison of clinical parameters, IVC measurements, and symptoms before and after HD is shown in Table 2. Among the parameters, body weight, IVC_{dmax}, IVC_{dmin}, and IVC_i significantly decreased after HD. Inferior vena cava collapsibility index remained unchanged. Blood pressure and heart rate were also relatively unchanged before and after HD. As for the symptoms, although overall occurrence was rare, there was improvement in the dyspnea/shortness of breath reported by patients after HD.

Examining further the relationship between symptoms and IVC measurement, it can be seen in Table 3 that those with any of the symptoms listed had higher absolute values of IVC_{dmax}, IVC_{dmin}, and IVC_i before HD. Change in the mentioned parameters, however, were significant for those without dyspnea and edema. Patients with symptoms also had lower values after HD, but the change was not significant. IVC collapsibility, on the other hand, did not significantly change. Those with orthopnea and other symptoms (chills, weakness, etc) also had lower IVC measures, which, however, did not meet statistical significance. These findings, however, are limited by the rare occurrence of symptoms in the study population.

Pearson correlations for change in weight and IVC measurements are listed in Table 4. Because none of the parameters have a $P < 0.05$, there is no correlation between change in weight and change in IVC_{dmax}, IVC_{dmin}, IVC_i, and IVC-CI.

Tables 5A and 5B compare the volume status classification by dry weight method with IVC_i and IVC-CI before and after dialysis. With the dry weight method, hypervolemia was defined as weight gain of ≥0.5 kg from dry weight, and hypovolemia as decrease in weight by ≥0.5 kg from dry weight.[4] For IVC_i, hypovolemia was defined by IVC_i <8 mm/m^2, euvolemia if ≥8 and ≤11 mm/m^2, and hypervolemia if IVC_i >11.5 mm/m^2. As for IVC-CI, a patient was hypovolemic if IVC-CI >75%, euvolemic if ≥40 and ≤75%, and hypervolemic if collapsibility <40%[4]. Comparing the IVC classifications with the dry weight method, it is evident that there are inconsistencies with the classification. Following dry weight and IVC-CI, most patients were hypervolemic before HD. After HD, however, only the dry weight classification showed change from hypervolemia to euvolemia; IVC-CI still showed a larger proportion of patients with hypervolemia, whereas IVC_i provided more hypovolemic patients compared with before HD. Table 6 summarizes the volume status in terms of weight, IVC-CI, and IVCi before and after HD for each participant in the study. .

DISCUSSION

This cross-sectional study investigated the utility of IVC measurements in determining the volume status of HD patients as compared with the dry weight method currently used. Findings showed that the current method of setting the UF rate did not result to any episodes of intradialytic hypotension or symptoms of hypovolemia among the 53 HD patients included. However, because heart rate, blood pressure, and IVC collapsibility did not change before and after HD despite significant changes in weight, it may be inferred that there is still room for additional volume removal among these patients, which weight change was not able to capture. This may be where POCUS for IVC measurement can supplement current practice.

Among the 53 patients monitored for the study, there were no documented incidences of intradialytic events. Patients with symptoms of hypervolemia before HD had relief of symptoms after HD. These suggest that the current dry weight method can determine an adequate UF rate for patients, enough to address symptoms and not cause hypovolemia. In this regard, IVC collapsibility measurements are not necessary to prevent such events.

A significant finding that the study provides, however, is how volume status based on IVC collapsibility and clinical objective measures such as heart rate and blood pressure is unchanged despite a significant decrease in weight. Absolute values for the IVC_{dmax}, IVC_{dmin}, and IVC_i significantly decreased before and after HD, along with the decrease in weight, as shown in Tables 2 and 3. This changes in IVC diameters (IVC_{dmax} and IVC_{dmin}) and IVC_i are in accordance with the findings of other studies. Shrestha el al[4] showed a statistically significant change in body weight and IVC diameters before and after dialysis. Collapsibility index, heart rate, and blood pressure likewise changed significantly in their study population, a finding not documented in this study. This is also corroborated by the findings of Hafiz et al,[1] wherein expiratory and inspiratory IVC and IVC collapsibility significantly changed in their population following dialysis, along with significant changes in weight, blood pressure, and heart rate. The difference in the findings may be

explained by discrepancies in the aggressiveness in setting UF rate during HD. The set UF rates in the mentioned studies were able to cause not only IVC changes, but also change in heart and blood pressure, and the studies documented higher incidences of intradialytic events (eg, 12 events in Shrestha and colleagues'[4] study). Although the UF rates set for this study's patients were sufficient to relieve symptoms and cause weight change, there was no change in the IVC measures, heart rate, and blood pressure, and only one intradialytic event was documented, which may or may not be attributed to hypovolemia. This suggests that the volume removed may not have caused a significant change in intravascular volume during the HD period or that equilibration with the third space quickly corrected the intravascular depletion caused by HD.

Another related finding is how absolute IVC measures are higher in patients considered to be clinically hypervolemic because of their symptoms (dyspnea, edema, etc), but which did not significantly change after HD, unlike in those without symptoms. This may suggest a need for other parameters of volume assessment to be used for these patients, as they may need higher UF rate targets to better address their hypervolemia. However, these findings are limited by the fact that only a few reported symptoms before HD. A sample with

Table 1A. Baseline Clinical Characteristics

Characteristics	Summary Measures
Age, y	58.28 ± 15.28
BSA, m^2	1.70 ± 0.2
BMI, kg/m^2	24.96 ± 5.78
Frequency of dialysis	
Two times a week	1 (1.89%)
Three times a week	49 (92.45%)
Four times a week	3 (5.66%)
Ultrafiltration rate, L	2.4 ± 0.768)
Sex	
Male	25 (47.17%)
Female	28 (52.83%)
Comorbidities	
Hypertension	48 (90.57%)
Diabetes mellitus	30 (56.60%)
Heart failure	22 (41.51%)
Glomerulonephritis	7 (13.21%)
Valvular heart disease	—
Coronary artery disease	9 (16.98%)
Other conditions	12 (22.64%)
Medications taken	
ACEI/ARB	20 (37.74%)
ARNI	12 (22.64%)
CCB	38 (71.70%)
β-Blockers	38 (71.70%)
α-Agonists	14 (26.42%)
α-Blockers	10 (18.87%)
Loop diuretics	6 (11.32%)
MRA	2 (3.77%)
SGLTI	1 (1.89%)
Nitrates	8 (15.09%)
ASA	14 (26.42%)
Ticagrelor	3 (5.66%)
Clopidogrel	18 (33.96%)
Statins	28 (52.83%)
Trimetazidine	9 (16.98%)
Other drugs	16 (30.19%)
Present symptoms	
Dyspnea/SOB	9 (16.98%)
Orthopnea	4 (7.55%)
Cough	2 (3.77%)
Chest pain/heaviness	—
PND	—
Edema	13 (24.53%)
Lightheadedness	1 (1.89%)
Other symptoms	7 (13.21%)
Events during HD	
Intradialytic hypotension	—
Lightheadedness	1 (1.89%)
Dyspnea/SOB	1 (1.89%)
Chest pain/heaviness	1 (1.89%)
Palpitations	1 (1.89%)

ACEI=angiotensin-converting enzyme inhibitor; ARB=angiotensin-receptor blocker; ARNI=angiotensin receptor–neprilysin inhibitor; ASA=acetylsalicylic acid; BMI=body mass index; BSA=body surface area; CCB=calcium-channel blocker; HD=hemodialysis; MRA=magnetic resonance angiography; PND=paroxysmal nocturnal dyspnea; SGLTI=sodium-glucose cotransporter inhibitor; SOB=shortness of breath.

Table 1B. Baseline Laboratory Characteristics

Characteristics	Summary Measures
LVEF	52.45 ± 9.97
Hemoglobin	99.72 ± 13.66
Hematocrit	0.31 ± 0.04
Creatinine	24.89 ± 116.35
eGFR	5.32 ± 1.87
Phosphorus	6.32 ± 2.40
BUN	52.73 ± 25.61
Calcium	6.78 ± 17.82
Sodium	133.46 ± 18.25
Potassium	4.61 ± 0.69

BUN=blood urea nitrogen; eGFR=estimated glomerular filtration rate; LVEF=left ventricular ejection fraction.
Values are presented as mean ± SD

Table 2. Clinical Characteristics Before and After Dialysis

Characteristics	Before HD	After HD	*P*
Body weight, kg	67.20 ± 15.39	65.14 ± 9.97	<0.01*
Heart rate	74.89 ± 4.49	76.81 ± 12.79	0.30
Systolic blood pressure	132.64 ± 13.32	133.02 ± 10.49	0.83
Diastolic blood pressure	78.30 ± 4.27	78.30 ± 7.00	0.99
IVC_{dmax}	1.91 ± 0.42	1.67 ± 0.38	<0.01*
IVC_{dmin}	1.24 ± 0.36	1.12 ± 0.33	0.03*
IVC_i	1.12 ± 0.24	0.99 ± 0.24	<0.01*
IVC-CI	34.67 ± 10.21	32.79 ± 11.74	0.33
Manifestations			
Dyspnea/SOB	9 (16.98%)	1 (1.89%)	0.01*
Chest pain/heaviness	0	1 (1.89%)	0.32
Lightheadedness	1 (1.89%)	1 (1.89%)	0.99

IVC-CI=inferior vena cava collapsibility index; IVC=indexed inferior vena cava diameter size; IVC_{dmax}=maximum inferior vena cava diameter; IVC_{dmin}=minimum inferior vena cava diameter; SOB=shortness of breath.
Values are presented as mean ± SD or n (%).
*Statistically significant.

Table 3. Symptoms and IVC Indices Before and After Dialysis

Characteristics	Before HD	After HD	*P*
Dyspnea (–) (n = 44)			
IVC_{dmax}	1.84 ± 0.37	1.60 ± 0.34	0.01*
IVC_{dmin}	1.21 ± 0.33	1.08 ± 0.35	0.03*
IVC_i	1.10 ± 0.24	0.96 ± 0.21	0.01*
IVC-CI	34.75 ± 10.77	32.75 ± 12.37	0.39

(continuation of Table 3)

Characteristics	Before HD	After HD	*P*
Dyspnea, % (n = 9)			
IVC_{dmax}	2.12 ± 0.50	2.01 ± 0.45	0.46
IVC_{dmin}	1.38 ± 0.28	1.33 ± 0.25	0.63
IVC_i	1.23 ± 0.23	1.18 ± 0.27	0.62
IVC-CI	34.32 ± 7.29	33.01 ± 8.59	0.43
Edema (–) (n = 40)			
IVC_{dmax}	1.82 ± 0.32	1.57 ± 0.30	0.01*
IVC_{dmin}	1.20 ± 0.30	1.03 ± 0.27	0.01*
IVC_i	1.10 ± 0.22	0.95 ± 0.20	0.01*
IVC-CI	34.29 ± 10.75	34.38 ± 11.86	0.97
Edema, % (n = 13)			
IVC_{dmax}	2.11 ± 0.55	1.98 ± 0.45	0.34
IVC_{dmin}	1.35 ± 0.40	1.43 ± 0.38	0.38
IVC_i	1.20 ± 0.30	1.14 ± 0.28	0.47
IVC-CI	35.87 ± 8.58	27.91 ± 10.30	0.01*
Orthopnea, % (n = 4)			
IVC_{dmax}	2.17 ± 0.59	1.68 ± 0.36	0.17
IVC_{dmin}	1.50 ± 0.31	1.22 ± 0.15	0.10
IVC_i	1.33 ± 0.25	1.04 ± 0.13	0.16
IVC-CI	29.84 ± 7.05	26.11 ± 6.47	0.39
Other symptoms, % (n = 7)			
IVC_{dmax}	2.13 ± 0.51	1.88 ± 0.51	0.06
IVC_{dmin}	1.44 ± 0.24	1.26 ± 0.24	0.05*
IVC_i	1.20 ± 0.27	1.06 ± 0.27	0.06
IVC-CI	31.29 ± 7.59	31.36 ± 7.86	0.95
Chest pain, % (n = 1)			
IVC_{dmax}	1.28	2.03	—
IVC_{dmin}	0.85	1.33	—
IVC_i	0.93	1.48	—
IVC-CI	33.59	34.32	—
Light-headedness, % (n = 1)			
IVC_{dmax}	1.72	1.54	—
IVC_{dmin}	1.14	1.04	—
IVC_i	0.92	0.82	—
IVC-CI	33.72	32.47	—

IVC=inferior vena cava; IVC-CI=inferior vena cava collapsibility index; IVC_i=indexed inferior vena cava diameter size; IVC_{dmax}=maximum inferior vena cava diameter; IVC_{dmin}=minimum inferior vena cava diameter.
Values are presented as mean ± SD.

Table 4. Correlation Between Change in Weight and Change in IVC Measurements

Causes	Correlation (95% CI)	*P*
Δ Weight and Δ IVC_{dmax}	0.086 (–0.189 to 0.348)	0.54
Δ Weight and Δ IVC_{dmin}	0.195 (–0.079 to 0.442)	0.16
Δ Weight and Δ IVC_i	0.060 (–0.213 to 0.325)	0.67
Δ Weight and Δ IVC-CI	–0.197 (–0.444 to 0.077)	0.16

95% CI=95% confidence interval; IVC=inferior vena cava; IVC-CI=inferior vena cava collapsibility index; IVC_i=indexed inferior vena cava diameter size; IVC_{dmax}=maximum inferior vena cava diameter; IVC_{dmin}=minimum inferior vena cava diameter.

Table 5A. Volume Status Before Dialysis

Volume Status Based on Weight	Volume Status Based on IVC_i				Volume Status Based on IVC-CI			
	Hypervolemia	Euvolemia	Hypovolemia	Total	Hypervolemia	Euvolemia	Hypovolemia	Total
Hypervolemia	23	23	4	50	37	13	0	50
Euvolemia	0	1	1	2	2	0	0	2
Hypovolemia	0	1	0	1	1	0	0	1
Total	23	25	5	53	40	13	0	53

IVC-CI=inferior vena cava collapsibility index; IVC_i=indexed inferior vena cava diameter size.

Table 5B. Volume Status After Dialysis

Volume Status Based on Weight	Volume Status Based on IVC_i				Volume Status Based on IVC-CI			
	Hypervolemia	Euvolemia	Hypovolemia	Total	Hypervolemia	Euvolemia	Hypovolemia	Total
Hypervolemia	2	9	5	16	14	2	0	16
Euvolemia	9	16	8	33	25	8	0	33
Hypovolemia	0	2	2	4	3	1	0	4
Total	11	26	15	53	42	11	0	53

IVC-CI=inferior vena cava collapsibility index; IVC_i=indexed inferior vena cava diameter size.

Table 6. Volume Status Before and After Dialysis

Patient	Before Dialysis			After Dialysis		
	Weight	IVC_i	IVC-CI	Weight	IVC_i	IVC-CI
1	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic
2	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
3	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic	Euvolemic	Hypervolemic
4	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
5	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Hypovolemic	Hypervolemic
6	Hypervolemic	Hypovolemic	Euvolemic	Hypovolemic	Hypovolemic	Hypervolemic
7	Euvolemic	Euvolemic	Hypervolemic	Euvolemic	Hypovolemic	Euvolemic
8	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic

(continuation of Table 6)

9	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic	Euvolemic
10	Hypervolemic	Hypovolemic	Euvolemic	Hypervolemic	Hypovolemic	Euvolemic
11	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Hypovolemic	Euvolemic
12	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Hypovolemic	Hypervolemic
13	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Euvolemic	Euvolemic
14	Euvolemic	Hypovolemic	Hypervolemic	Hypovolemic	Hypovolemic	Hypervolemic
15	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic	Hypovolemic	Euvolemic
16	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic	Hypovolemic	Hypervolemic
17	Hypovolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
18	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
19	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
20	Hypervolemic	Euvolemic	Euvolemic	Euvolemic	Euvolemic	Hypervolemic
21	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic
22	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
23	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Hypovolemic	Hypervolemic
25	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
26	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
27	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
28	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
29	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic
30	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic
31	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
32	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic
33	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
34	Hypervolemic	Hypovolemic	Hypervolemic	Euvolemic	Hypovolemic	Hypervolemic
35	Hypervolemic	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
36	Hypervolemic	Hypervolemic	Hypervolemic	Hypovolemic	Euvolemic	Euvolemic
37	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
38	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic
39	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic	Hypervolemic
40	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic
41	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Euvolemic	Euvolemic
42	Hypervolemic	Euvolemic	Euvolemic	Euvolemic	Hypovolemic	Hypervolemic
43	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic	Hypervolemic
44	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Euvolemic

(continuation of Table 6)

45	Hypervolemic	Hypervolemic	Euvolemic	Euvolemic	Euvolemic	Hypervolemic
46	Hypervolemic	Hypervolemic	Hypervolemic	Euvolemic	Hypervolemic	Hypervolemic
47	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Hypovolemic	Hypervolemic
48	Hypervolemic	Hypervolemic	Hypervolemic	Hypovolemic	Euvolemic	Hypervolemic
49	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Euvolemic
50	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
51	Hypervolemic	Hypovolemic	Hypervolemic	Euvolemic	Hypovolemic	Hypervolemic
52	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic
53	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Hypovolemic	Hypervolemic
54	Hypervolemic	Euvolemic	Hypervolemic	Euvolemic	Euvolemic	Hypervolemic

IVC-CI=inferior vena cava collapsibility index; IVC_i=indexed inferior vena cava diameter size.

higher prevalence of symptoms, such as admitted patients or those recently initiated on HD, may better characterize this relationship.

As in other studies, a large discrepancy between clinical estimates of volume status based on weight and those based on IVC_i and IVC-CI is seen. According to weight gain and IVC-CI, the majority of patients were hypervolemic before HD, but only half based on IVC_i. There was more congruence with IVC-CI and weight change before HD. After HD, however, there were more euvolemic patients based on weight change and IVC_i, whereas a majority was still hypervolemic by IVC-CI. Like the findings mentioned earlier, this shows that patients may have been labeled as euvolemic or hypovolemic by dry weight but were actually still hypervolemic by collapsibility index. This assumes that IVC-CI is a more useful parameter of volume status, as is documented in previous studies, with a sensitivity of 71% and specificity of 81% for spontaneously breathing patients.[5] Shrestha et al[4] and Hafiz et al[1] both found the large discrepancies in categorization based on weight and IVC measurements as well, although both used only IVC-CI. Because there is no criterion-standard test that can be easily performed on the bedside, taking into account multiple parameters may provide a better guidance to patients' volume status.

LIMITATIONS

The results of the study should be interpreted in light of certain limitations. In terms of IVC indices, values are subject to interindividual variations and several factors that may affect measurement. Also, there are also no standardized cutoff values for IVC_i and IVC-CI to categorize as hypovolemic, euvolemic, and hypervolemic. This study followed the classification from related literature, but this may not be the standard for the subset of patients included in the study. Inferior vena cava also measures only the intravascular space; hence, this should be interpreted along with other parameters that provide a more holistic measure of fluid status. More invasive but accurate measures of hemodynamic status were also not used in this study, which could have served as the criterion standard to compare the accuracy of IVC measures. As for the study being cross-sectional in design, data were obtained at only one point in time and therefore may not capture events after the HD session. Also, only one investigator performed the knobology to avoid disrupting the dialysis schedule, as measurements had to be taken before starting and immediately at the end of HD. The small sample size and low incidence of symptoms may also limit the conclusions that can be drawn. Lastly, measurements obtained are affected by the limitations in image quality of the Butterfly iQ handheld ultrasound, compared with the standard 2D echocardiogram.

CONCLUSION

This pilot study was able to show that the current method of dry weight and clinical assessment allows estimation of UF rate without causing intradialytic hypotension and hypovolemia among stable patients. In this aspect, IVC collapsibility may not be necessary to prevent these events. However, IVC measurements using POCUS, given its increasing availability and accessibility, may aid in providing additional parameters to increase volume removal enough to cause a change in intravascular volumes, especially in hypervolemic patients with symptoms. Point-of-care ultrasound measurements can be an additional parameter to target for higher UF rates to be set, which may lead to fewer hypervolemia symptoms in between HD sessions. Given the incongruencies in classifying volume status according to the different measures, no single measure is sufficient to determine hemodynamic status in HD patients. Inferior vena cava indices can supplement weight, blood pressure, heart rate, and patient symptoms for a more accurate and holistic determination of volume status among HD patients.

With this, the study supports the usefulness of IVC measurement through POCUS for patients on HD as additional measure of hemodynamic status and in setting the target UF rate. Further studies with larger sample sizes or multiple

measurements through time may help provide more information on the matter, as well as studies on symptomatic and/or critically ill patients to better determine the association between symptoms and IVC indices.

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