

Handcarried Ultrasound Measurement of the Inferior Vena Cava for Assessment of Intravascular Volume Status in the Outpatient Hemodialysis Clinic

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Accurate intravascular volume assessment is critical in the treatment of patients who receive chronic hemodialysis (HD) therapy. Clinically assessed dry weight is a poor surrogate of intravascular volume; however, ultrasound assessment of the inferior vena cava (IVC) is an effective tool for volume management. This study sought to determine the feasibility of using operators with limited ultrasound experience to assess IVC dimensions using hand-carried ultrasounds (HCU) in the outpatient clinical setting. The IVC was assessed in 89 consecutive patients at two outpatient clinics before and after HD. Intradialytic IVC was recorded during episodes of hypotension, chest pain, or cramping. High-quality IVC images were obtained in 79 of 89 patients. Despite that 89% of patients presented at or above dry weight, 39% of these patients were hypovolemic by HCU. Of the 75% of patients who left HD at or below goal weight, 10% were still hypervolemic by HCU standards. Hypovolemic patients had more episodes of chest pain and cramping (33 versus 14%, $P = 0.06$) and more episodes of hypotension (22 versus 3%, $P = 0.02$). The clinic with a higher prevalence of predialysis hypovolemia had significantly more intradialytic adverse events (58 versus 27%; $P = 0.01$). HCU measurement of the IVC is a feasible option for rapid assessment of intravascular volume status in an outpatient dialysis setting by operators with limited formal training in echocardiography. There is a poor relationship between dry weight goals and IVC collapsibility. Practice variation in the maintenance of volume status is correlated with significant differences in intradialysis adverse events.

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Volume regulation is among the most critical yet challenging aspects of dialysis therapy. Chronic hypervolemia leads to hypertension, structural heart disease, and pulmonary edema (1–6), and intradialytic hypovolemia is associated with cramps, nausea, vomiting, and decreased patient satisfaction (7–11). Intradialytic hypotension is one of the most frequent complications of hemodialysis (HD); its incidence varies from 10 to 30% of sessions, depending on the population studied (12). There is no simple mechanism to explain hypotension, because many interrelated factors may be involved in the pathogenesis. The evaluation of a patient's volume status is difficult with traditional clinical tools. Clinically assessed dry weights, defined as the lowest postdialysis weight at which most excess body fluid will have been removed, are widely used but poorly predictive of volume status. In addition, bedside clinical assessment of volume status is grossly inadequate (13–15).

As a result, several methods have been developed for the

assessment of volume status, including bioimpedance, blood volume monitoring, and the tracking of biochemical markers. However, each of these has significant theoretical and practical limitations (16,17). One of the most promising techniques for monitoring intravascular volume involves ultrasound assessment of the indexed inferior vena cava diameter (VCDi) and collapsibility index (IVCCI), which have been shown to be accurate measures of right atrial pressure and volume status in HD patients (18–21). Titration of dry weights to a VCDi between 8.0 and 11.5 mm/m² (correlating with a right atrial pressure of 3 to 7 mmHg) significantly decreases intradialysis adverse events, left ventricular mass, and left atrial size as well as improves quality of life (22–24). However, barriers to the widespread implementation of an echocardiographic method in outpatient dialysis clinics include the cost and availability of conventional ultrasound machines, as well as the specialized training that is necessary for operation of these platforms. The introduction of hand-carried cardiac ultrasound (HCU) devices, which are relatively inexpensive and portable, has allowed bedside cardiac evaluation at the time of physician encounter in numerous settings (25–27). Recent studies have demonstrated acceptable accuracy when limited HCU examinations were performed by noncardiologists (28,29). HCU devices have proved accurate when compared with standard

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echocardiograms for assessing IVCCI (30). When compared with right heart catheterization, an HCU-determined IVCCI has excellent accuracy for detecting elevated right atrial pressure (30,31). In this study, we sought to determine whether noncardiologists with limited ultrasound training could assess accurately intravascular volume status and predict intradialytic adverse events using an HCU device in an outpatient HD center.

Materials and Methods

Eighty-nine chronic HD patients were enrolled and studied at two outpatient dialysis clinics. All patients who presented for HD between 7 a.m. and 9 p.m. at each of the two centers were approached regarding involvement in the study. Patients were enrolled consecutively without regard for body habitus, the quality of their echocardiographic images, medical history, or any other screening criterion. Baseline demographics including pre-, post-, and target weights as well as dialysis duration were recorded. Intradialytic events, defined as hypotension (systolic BP <100 mmHg) or significant subjective patient symptoms (cramping or chest pain) that required alteration of the HD session, were detected by staff nurses and dialysis technicians and brought to the attention of the resident physicians who were readily available throughout each session.

Patients underwent a brief echocardiographic examination, using an HCU device (Optigo; Philips Medical, Andover, MA). This 6.6-pound device consists of a base unit, a phased-array 2.5-MHz transducer, and a battery. The retail price for this device was approximately \$12,000 to \$15,000. This platform provides both two-dimensional and color Doppler echocardiographic images and has a limited number of controls for adjusting imaging depth and gain. Images can be frozen and scrolled for on-line review. Image quality was rated subjectively as poor, fair, or good depending on the clarity of the IVC walls. Poor-quality images were omitted from our analysis.

Medical residents with minimal echocardiographic exposure and no previous formal training in ultrasonography performed the HCU studies. The physicians underwent 4 h of formal didactic training and performed 20 supervised patient measurements of the IVC from the subcostal approach. Each patient's IVC was assessed while reclining in the supine position on an examination room table or in the patient's dialysis chair. Measurements were taken immediately before and within 30 min after each dialysis session. In addition, when possible, an intradialytic IVC assessment was obtained at the time of symptoms (cramping, chest pain) or hypotension that required alterations in dialysis therapy.

After visualization of the IVC, a loop was acquired taking care to maximize the IVC diameter throughout the respiratory cycle. Images then were frozen and scrolled to find the maximal IVC diameter (IVC_{max}) during passive respiration within 2.5 cm of the IVC-RA junction. Patients then were asked to take a short, quick inspiratory effort or "sniff." Minimum IVC diameter (IVC_{min}) was measured as the smallest IVC size recorded during the sniff. Indexed IVC size (VCDi) was calculated by dividing IVC_{max} by the body surface area (BSA; m^2). Inferior vena cava collapsibility index (IVCCI) was calculated using the standard formula $[(IVC_{max} - IVC_{min})/IVC_{max}] \times 100$.

The accuracy of volume assessment by dry weight was determined through a comparison with established VCDi and IVCCI cutoffs (Table 1) (18,22,23). Patients were considered to be at goal weight when they were within 0.5 kg of their preestablished dry weight.

A brief poststudy survey that assessed overall satisfaction, ease of use, disruption of patient flow, and average study duration was completed by the physicians who obtained the HCU measurements as well as the attending clinical nephrologists.

Table 1. VCDi and IVCCI cutoffs^a

	VCDi (mm/m^2)	IVCCI (%)
Hypovolemia	<8	>75
Euvolemia	≥ 8 and ≤ 11.5	≥ 40 and ≤ 75
Hypervolemia	>11.5	<40

^aIVCCI, inferior vena cava collapsibility index; VCDi, inferior vena cava diameter.

Statistical Analyses

The *t* test and χ^2 test were used for data analysis. Results are presented as mean \pm SD. A two-tailed *P* < 0.05 was considered to represent a statistically significant difference. In an attempt to examine the effect of practice style variations on volume status and event rates, we calculated mean VCDi and IVCCI measurements separately for both dialysis clinics. The University of Chicago institutional review board approved the protocol.

Results

Study Population

Of the 89 patients enrolled, 10 had an IVC image that was poor and therefore omitted from analysis. Baseline patient demographics and treatment-related measures are presented in Table 2. On average, patients presented 2.1 kg above their established dry weight, underwent 230 min of HD, and left dialysis 0.1 kg below dry weight. Mean BSA differed significantly between patients in whom fair and good image quality was observed (1.92 ± 0.23 versus 1.78 ± 0.24 m^2 ; *P* = 0.04)

Volume Assessment

Large discrepancies were noted between weight-based and HCU-based assessments of volume status both before and after dialysis (Table 3). Before HD, the vast majority (89%) of patients were above their established dry weight. However, depending on whether IVCCI or VCDi criteria were used, 39 to 47% of these patients were hypovolemic by HCU standard. An additional 21 to 25% were euvolemic before HD despite being above their dry weight.

After dialysis, similar discrepancies between dry weight and HCU also were noted. By weight criteria, 75% of patients had sufficient fluid removed to get to goal weight. However, only 13 to 19% of these patients were actually euvolemic using IVC measurements. A small proportion of HD patients who were at or below goal weight were still hypervolemic (9 to 10%), and nearly half (47 to 54%) were hypovolemic. No significant correlation was found between change in body weight and change in VCDi (*r* = 0.14, NS), and there was a weak correlation between change in weight and change in IVCCI (*r* = -0.25, *P* = 0.03).

Event Assessment

One or more events was experienced by 29 (37%) of the patients in this study. Eleven of these events involved hypotension (systolic BP <100 mmHg), and 18 involved chest pain or cramping that necessitated alteration of HD. Of patients in whom the IVC was assessed during an event (*n* = 11), 92%

Table 2. Baseline patient characteristics^a

	Overall	Clinic 1	Clinic 2	Clinic 1 versus Clinic 2
Age (yr)	58 ± 17	56 ± 18	62 ± 14	NS
BSA (m ²)	1.8 ± 0.2	1.8 ± 0.2	1.9 ± 0.2	NS
No. of sessions/wk	3	3	3	NS
Length of HD (min)	230 ± 32	225 ± 29	243 ± 33	0.017
Goal weight (kg)	72 ± 19	69 ± 16	80 ± 21	0.02
Pre-HD weight (kg)	74 ± 20	71 ± 18	82 ± 22	0.02
Pre-HD goal weight (kg)	2.1 ± 1.9	1.7 ± 1.9	3.0 ± 1.7	0.006
Post-HD weight (kg)	72 ± 19	69 ± 17	79 ± 21	0.025
Total weight loss (kg)	2.2 ± 1.2	2.0 ± 1.1	2.6 ± 1.4	0.04
Post-HD goal weight (kg)	-0.1 ± 1.3	-0.3 ± 1.5	0.4 ± 0.6	0.05
Pre-HD SBP (mmHg)	144 ± 22	144 ± 20	143 ± 25	NS
Minimum HD SBP (mmHg)	120 ± 24	123 ± 24	115 ± 25	NS
Pre-HD IVC _{max} (mm)	15 ± 6	16 ± 6	13 ± 4	0.06
Pre-HD VCDi (mm/m ²)	8.6 ± 4	9.3 ± 4	7.1 ± 2	0.013
Pre-HD IVCCI (%)	60 ± 30	57 ± 30	65 ± 30	NS
Post-HD IVC _{max} (mm)	13 ± 6	14 ± 6	11 ± 4	0.014
Post-HD VCDi (mm/m ²)	7.4 ± 3	8.1 ± 4	5.8 ± 3	0.007
Post-HD IVCCI (%)	72 ± 20	69 ± 30	80 ± 20	0.056

^aBSA, body surface area; HD, hemodialysis; IVC_{max}, maximal IVC diameter; SBP, systolic BP.

Table 3. Percentages of patients before and after HD above or below goal weight broken down by VCDi and IVCCI volume status

	Weight (%)			
	Before HD		After HD	
	Goal	Over	Goal	Over
VCDi				
echo, low	6	47	47	11
echo, goal	1	21	19	10
echo, over	4	21	10	3
IVCCI				
echo, low	6	39	54	6
echo, goal	1	25	13	10
echo, over	4	24	9	9

were found to be hypovolemic by VCDi and 73% were hypovolemic by IVCCI.

There was a trend for intradialytic chest pain or cramping to be more common in patients with predialysis hypovolemia by VCDi. Patients with a pre-HD VCDi of <8 mm experienced chest pain/cramping 33% of the time versus those with a VCDi >8 mm, for whom the frequency was 14% ($P = 0.06$). There was a similar trend for more frequent chest pain/cramping among pre-HD hypovolemia defined with an elevated versus normal IVCCI, for which the rates of were 30 and 18%, respectively ($P = 0.19$). Intradialytic chest pain/cramping was not significantly different among patients in the highest and lowest quartiles of total weight removal or predialysis weight above goal weight.

Intradialytic hypotension was not predicted by pre-HD HCU-defined hypovolemia (low VCDi or high IVCCI). In fact, hypotensive episodes were significantly more common in patients with a low predialysis IVCCI (22 versus 3%; $P = 0.02$); that is, in patients who were euvolemic or hypervolemic. There was also a trend for more intradialysis hypotension in patients who presented at the highest level above their goal weight (21 versus 6%; $P = 0.17$ for highest and lowest quartiles).

Effects of Practice Variation

Age and number of weekly dialysis sessions did not differ between clinics 1 and 2 (Table 2). However, patients from clinic 2 underwent significantly longer dialysis sessions than did those at clinic 1 (243 versus 225 min; $P = 0.017$). Patients in clinic 2 presented to HD significantly more over their goal weight (3.0 versus 1.7 kg; $P = 0.006$), had more volume removed (2.6 versus 2.0 kg; $P = 0.04$), yet left dialysis on average above goal weight (0.4 versus -0.3; $P = 0.05$).

By HCU standards, patients in clinic 1 presented in the middle range of euvoolemia (VCDi 9.3 and IVCCI 57%) and left dialysis at the lower end of euvoolemia (VCDi 8.1 and IVCCI 69%). Clinic 2 patients presented hypovolemic by VCDi (7.1; $P = 0.013$ versus clinic 1) and euvolemic by IVCCI (65%). After dialysis, clinic 1 patients left hypovolemic by both VCDi (5.8; $P = 0.007$ versus clinic 1) and IVCCI (80%; $P = 0.056$ versus clinic 1).

Event rates were significantly higher at clinic 2 than at clinic 1 (58 versus 27%; $P = 0.01$). This elevated event rate was primarily due to a much higher rate of chest pain/cramping that required alterations in dialysis at clinic 2 (42 versus 15%; $P = 0.01$) as well as a trend to more hypotension (11 versus 21%; $P = 0.24$).

Physician Satisfaction

Each of the four physicians who were involved in obtaining the ultrasound measurements rated overall satisfaction and ease of use as “above average” or “excellent.” All four resident physicians and both attending clinical nephrologists rated the technique as either “not disruptive” or “minimally disruptive” to patient care. According to the operators, each study took an average of 3 to 5 min.

Discussion

The bedside assessment of VCDi and IVCCI by operators with limited formal training using HCU machines is feasible in a busy outpatient dialysis clinic. The rate of high-quality image acquisition (89%) was somewhat lower than previously reported (94 to 95%), but the previous studies used experienced sonographers on full echocardiographic platforms (20,32). A feasibility rate of nearly 90% given the more limited expertise and equipment used in our study is excellent and similar to previous results using an HCU in the hands of noncardiologists (28). As expected, BSA had a significant impact on image quality. In addition, physician satisfaction with the technique was excellent and when properly coordinated did not disrupt patient care.

The assessment of IVCCI by HCU previously was proved to be accurate when compared with standard echocardiograms with 96% agreement ($\kappa = 0.87$) between the two systems (30). In addition, HCU IVCCI <50% corresponded to a right atrial pressure >10 mmHg with a 95% agreement ($\kappa = 0.89$) in 20 patients who were referred for right heart catheterization (30). A recent study that was performed by resident physicians who had limited ultrasound training and used HCU devices on 102 patients who were referred for right heart catheterization demonstrated that an IVCCI <40% was highly predictive of right atrial pressure >10 mmHg (31).

As in other studies, our data show a large discrepancy between clinical estimates of volume status that are based on dry weight and those that are based on VCDi or IVCCI. Similar to previous analyses, we have shown that approximately 50% of patients arrived at dialysis in a state of intravascular dehydration (18). In addition, 13 to 18% of patients left dialysis intravascularly volume overloaded. As may be anticipated, patients who began dialysis in a state of intravascular hypovolemia had strong trends for an increased rate of treatment-altering intradialytic adverse events such as chest pain or cramping. This observation is in agreement with data previously presented by Chang *et al.* (23). This was supported additionally by finding that nearly all (92%) patients had IVC-defined hypovolemia when imaged during their HD adverse event.

Unexpected, patients who were hypervolemic by IVCCI before dialysis were more likely to experience intradialytic hypotension than those who were euvolemic or hypovolemic. This trend may have been due to more aggressive fluid removal goals in hypervolemic patients. This is supported by the trend for patients who presented highest above their dry weight to have more intradialytic hypotension.

Another interesting finding in this study involves the clinic-to-clinic variation that we observed in dry weight titration. In

our study, the patients in clinic 1 were maintained both before and after dialysis within the euvolemic thresholds of VCDi and IVCCI. Clinic 2 was more aggressive at fluid removal. The patients were already in the hypovolemic range before dialysis by VCDi criteria and had a greater net weight loss during HD than clinic 1 patients. In addition, these patients left HD, on average, hypovolemic by both HCU criteria. One may speculate that the longer duration of time for dialysis allows for more time for fluid removal and therefore a lower number of complications, including hypotension. The results of this study showed the reverse. Clinic 1 had shorter treatment times, larger intradialytic volume gain, and fewer number of adverse events.

These findings certainly may explain the significantly higher rate of intradialytic adverse events in clinic 2 patients. The mean pre- and postdialysis VCDi for clinic 2 (7.1 and 5.8 mm/m²) were below the value previously demonstrated to correlate with an increased adverse event rate and decreased quality of life (8.0 mm/m²) (23,24). In contrast, the pre- and postdialysis VCDi for clinic 1 (9.3 and 8.1 mm/m²) were above this limit (yet below the 11.5 mm/m² shown to correlate with an increase in left ventricular mass and left atrial diameter). Although the sample size for the two cohorts was relatively small, these results do seem to validate the observations by Chang *et al.* that “drier is not always better.”

Limitations

The major limitation of this technique is the optimal timing of postdialysis measurements. Re-equilibration of interstitial and intravascular compartments may continue up to 2 h after a 3-h dialysis session (19,33). Therefore, postdialysis assessments ideally should take place 2 h after therapy. If performed on a regular basis, then this would represent a significant drain on available resources, and patient compliance almost certainly would be low. However, a recent longitudinal trial of this technique found that most patients require dry weight titrations at no more than 3- to 4-mo intervals (24). On the basis of these data, one reasonable approach would entail an initial period of active IVC assessment and dry weight titration followed by periodic reassessment at 3- to 4-mo intervals.

Conclusions

Ultrasound assessment of IVC dimensions can be performed by operators with limited echocardiographic experience in a busy outpatient HD clinic using handheld ultrasound devices. Significant differences exist between weight-based and HCU-based estimations of volume status. Use of HCU to determine euvolemia may help to reduce intradialytic adverse events and prevent long-term cardiovascular complications. On the basis of these results, a larger scale outcomes study that longitudinally incorporates this technology into daily practice should be undertaken.

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