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Original Article

Use of Handheld Ultrasound to Estimate Fluid Status of Hemodialysis Patients

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ABSTRACT

Introduction: Accurate assessment of fluid status in hemodialysis patients presents a significant challenge. Nephrologists have long relied on dry weight estimation based solely on clinical parameters to decide the ultrafiltration volume for patients with end-stage kidney disease on dialysis. However, this method is far from accurate and many patients recurrently suffer from signs and symptoms of fluid overload or circulatory collapse from overaggressive ultrafiltration. Invasive methods such as measurement of central venous pressure cannot be used routinely. We evaluated the usefulness of inferior vena cava (IVC) diameter measured by handheld ultrasound in the estimation of fluid status in patients before and after hemodialysis.

Materials and Methods: Clinical assessment included patients' symptoms, weight, blood pressure, heart rate, and presence of edema before and after dialysis session. Dry weight was assessed based on the above parameters. Each patient underwent measurement of inferior vena cava before and after hemodialysis. The anteroposterior IVC diameter (IVCD) was measured 1.5 cm below the diaphragm in the hepatic segment in supine position during normal inspiration and expiration.

Results: Thirty hemodialysis patients (mean age 51.6±18.03 years) were evaluated in outpatient dialysis unit. Following hemodialysis mean IVCe (IVC diameter in expiration) decreased from 1.40±0.38 to 0.91±0.30 cm ($p<0.001$). Similarly, mean IVCi (IVC diameter in inspiration) decreased from 0.67±0.34 to 0.35±0.19 cm ($p<0.001$). Changes in IVCD were significantly correlated with alterations in body weight following dialysis ($p<0.0001$). The IVC collapsibility index (IVC-CI, per cent of change in IVC diameter in expiration vs. inspiration) increased significantly from 0.53±0.18 to 0.68±0.18 after dialysis ($p=0.002$). IVC diameter and IVC-CI clearly reflected alterations in fluid status. Regarding the clinical parameters of fluid status, following hemodialysis, mean heart rate increased from 81.17±5.21 beats per minute to 86.50±7.99, ($p=0.003$), systolic blood pressure increased from 148.67±26.36 mmHg to 155.00±28.50, ($p=0.05$), and diastolic blood pressure increased from 78.62±12.74 mmHg to 84.83±14.55, ($p<0.001$).

Conclusions: Our findings support the applicability of IVCD measurement and IVC-CI in the estimation of fluid status in end stage kidney disease patients on hemodialysis. The clinical parameters of fluid status including heart rate, systolic blood pressure, and diastolic blood pressure suggest that significant numbers of patients underwent excess ultrafiltration based on their traditional dry weight calculation. Thus, using IVC parameters before and during hemodialysis might give a better estimation of fluid status of the patient and guide the amount of ultrafiltration to be done.

Keywords: Central venous pressure; Dry weight; Fluid status; Handheld ultrasound; Inferior vena cava;

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Sodium and fluid retention in end stage kidney disease (ESKD) patients are associated with worsening fluid overload (FO) with accompanying hypertension and vascular changes which lead to serious cardiovascular complications. Chronic FO, pressure overload, and anemia lead to left ventricular hypertrophy (LVH), diastolic dysfunction, and ultimately dilatation of heart with resulting cardiomyopathy and congestive heart failure. In hemodialysis (HD) patients, the maintenance of circulating blood volume within an optimal range is critical to avoid circulatory complications.[1] As positive sodium balance and the resultant FO represent the two major causes of hypertension and increased cardiovascular mortality in patients with ESKD, the amount of fluid to be removed from a patient at dialysis is of utmost importance. In a functional kidney, removal of excess sodium and fluid through homeostatic mechanisms restores normal extracellular volume. In ESKD patients on HD achievement of euvolemia is dependent on the expertise and skills of the treating physician. Talking about current practice of dry weight measurement, it may be defined as the post-dialysis weight at which blood pressure remains normal during the interdialytic period without use of anti-hypertensives despite weight increase. However, considering the financial conditions of most of the patients in a country like Nepal, most patients do not get an adequate number of HD treatments. This is one of the greatest factors responsible for inadequate control of blood pressure despite the prescription of multiple antihypertensive drugs of almost all available classes. Because of inadequate frequency of dialysis there is a large increase in fluid in the inter-dialytic period and also a corresponding large amount of ultrafiltration that must be done during dialysis to remove the excess fluid and achieve dry weight. The main problem is how to determine the dry weight. Current practice is determination of dry weight by measurement of clinical parameters including symptoms of hyper- or hypovolemia, vital signs, and physical exam findings of FO such as rales and edema. However, the dry weight recorded in the patient file is not a constant value and may vary between HD sessions, requiring revision at each session. For instance, misinterpretation of anabolic weight gain may lead to hypovolemia if the patient is allowed to complete the dialysis with the same weight, or inversely, misinterpretation of weight loss because of increased catabolism may lead to hypervolemia if the same weight is maintained.

Patient history may provide some useful information on the volume status. Non-adherence with sodium restriction combined with hypertension and symptoms such as headache, dyspnea, and orthopnea suggests hypervolemia. In contrast, cramps, fatigue, and orthostatic hypotension suggest hypovolemia. However, such symptoms have a low sensitivity and high inter-patient variability. A hypervolemic patient may have the symptoms of hypovolemia at the end of dialysis because of high ultrafiltration (UF) rate. This happens because of the compartmentalization of fluids. HD removes fluid from the intravascular space and it is refilled from the extracellular fluid. Until adequately filled the patient may have symptoms of hypovolemia Changes in the IVCD, and replace with IVC-CI, as measured by bedside ultrasonography have been considered a useful parameter to assess right sided cardiac function and estimate central venous pressure (CVP).[2,3] The measurement of inferior vena cava diameter (IVCD) by ultrasonography has been suggested as a reliable method for evaluation of fluid status in HD patients.[4-5] In this study, we used handheld portable ultrasound machine to measure the diameter of IVC during inspiration and expiration and calculate the collapsibility index of IVC, before and immediately after hemodialysis to assess their fluid status and compare with the traditional dry weight method used to decide the amount of ultrafiltration.

Table 1: Fluid volume status based on IVC-CI and dry weight

	Volemic Status based on IVC-CI	Volemic status based on dry weight
Hypervolemia	CI <0.40	Body Wt< Dry wt - 0.5
Euvolemia	0.40 ≤ CI ≤ 0.75	Dry wt - 0.5 ≤ Body Wt≤ Dry wt + 0.5
Hypovolemia	>0.75	Body Wt> Dry wt + 0.5

MATERIALS AND METHODS

Patients with kidney disease and undergoing hemodialysis were assessed in the hemodialysis unit of Patan Hospital, a tertiary care general hospital in the Kathmandu Valley of Nepal. All patients were treated for 3 to 4 hours, two to three times per week. Weight was measured before and after dialysis. Fluid status was estimated according to the standard of care dry weight assessment as well as IVC-CI (Table 1). Periorbital and pretibial edema, dyspnea, orthopnea and hypertension were considered as signs of fluid overload. Muscle cramps, dizziness, hypotension and tachycardia indicated decreased fluid load. Rise in heart rate, systolic, and diastolic blood pressure (paradoxical hypertension) after dialysis were also taken as indicator of decreased fluid load or excess ultrafiltration. Paradoxical hypertension, defined as increase in blood pressure during UF, is explained on the basis of hypovolemia activating renin-angiotensin-aldosterone system during UF.[7]

Ultrasonographic studies were performed immediately before and after the dialysis session. The ultrasound used was manufactured by GE Healthcare called Vscan™, which is a handheld, pocket-sized ultrasound tool that provides real-time black-and-white anatomic and color-coded blood flow images. The transducer used was cardiac probe. Each parameter, IVCe and IVCi, was measured twice and the average was recorded. The anteroposterior IVC diameter was measured using 2 - dimensional recordings 1.5cm below the diaphragm in the hepatic segment in the supine position after 5–10 min of rest during normal expiration and inspiration while trying to avoid Valsalva maneuvers (fig. 1). The same examiner performed all the measurements of IVCD. IVC-CI was determined as the percent of decrease in IVC diameter in inspiration compared to expiration (maximum diameter of IVC on expiration minus minimum diameter of IVC on inspiration divided by maximum diameter on expiration multiplied by 100), or (IVC max exp – IVC min insp / IVC max exp) × 100.

Results are reported as mean±SD. IVC diameter, heart rate, systolic and diastolic blood pressure before and after ultrafiltration were compared by paired t- test. Pearson correlation coefficients (r) and the significance for it (p) were calculated between the values. P values less or equal to 0.05 were considered statistically significant.

RESULTS

A total of 30 HD patients (12 women and 18 men) were included in the study. The patients' ages ranged from 33 to 69 years with a mean of 51.6±18.03 years (Table 2). The range of dialysis vintage was 1–5 years. The mean dry weight was 51.43 kg (51.43 ± 10.01). The patient characteristics were distributed normally except IVCi before dialysis (Table2). Following HD mean IVCe decreased from 1.40±0.38 to 0.91±0.30 cm (P<0.001) as shown in table 3. Similarly, mean IVCi decreased from 0.67±0.34 to 0.35±0.19 cm

Table 2: Patient characteristics

Variable	n	Mean	Std Deviation	Skewness	Std error of Skewness
Age (years)	30	51.60	18.03	-0.29	0.43
Dry Weight (kg)	30	51.43	10.01	0.25	0.43
Last UF (ml)	30	2135.00	1299.21	0.17	0.43
Body weight before dialysis (kg)	30	52.42	10.30	0.16	0.43
Body weight after dialysis (kg)	30	50.19	10.10	0.30	0.43
Heart rate before dialysis (beats/min)	30	81.17	5.21	-0.52	0.43
Heart rate after dialysis (beats/min)	30	86.50	7.99	0.43	0.43
Systolic BP before dialysis (mmHg)	30	148.67	26.36	-0.11	0.43
Systolic BP after dialysis (mmHg)	30	155.00	28.50	0.21	0.43
Diastolic BP before dialysis (mmHg)	30	78.62	12.74	0.62	0.43
Diastolic BP after dialysis (mmHg)	30	84.83	14.55	-0.19	0.43
IVCe before dialysis (cm)	30	1.40	0.38	-0.24	0.43
IVCe after dialysis (cm)	30	0.91	0.30	-0.07	0.43
IVCi before dialysis (cm)	30	0.67	0.34	1.05	0.43
IVCi after dialysis (cm)	30	0.35	0.19	0.65	0.43
Ultrafiltrate (mL)	30	2230.80	1356.44	0.14	0.43
Collapsibility Index before dialysis	30	0.53	0.18	-0.55	0.43
Collapsibility Index after dialysis	30	0.68	0.18	-0.14	0.43

Table 3: Comparison of parameters before and after dialysis

Variables	Before Dialysis	After Dialysis	P-value *
Body Weight (Kg)	52.42 ± 10.30	50.19 ± 10.10	<0.001
Heart Rate	81.17 ± 5.21	86.50 ± 7.99	0.003
Systolic BP	148.67 ± 26.36	155.00 ± 28.50	0.05
Diastolic BP	78.62 ± 12.74	84.83 ± 14.55	0.036
IVCe	1.40 ± 0.38	0.91 ± 0.30	<0.001
IVCi	0.67 ± 0.34	0.35 ± 0.19	<0.001
Collapsibility Index	0.53 ± 0.18	0.68 ± 0.18	0.002

(* using paired t test)

Table 4: Correlation between ultrafiltrate volume and change in IVC diameters

	n	R	p-value
Ultrafiltrate and Δ IVCe	30	0.40	0.028
Ultrafiltrate and Δ IVCi	30	0.32	0.039

(p<0.001). Changes in IVCD were significantly correlated with alterations in body weight following dialysis (p<0.0001). The IVC-CI (per cent of change in IVC diameter in expiration versus inspiration) increased significantly after dialysis (P=0.002). IVCD and its IVC-CI reflected alterations in fluid status. Regarding the clinical parameters of fluid status, following HD mean heart rate increased from 81.17±5.21 beats per minute to 86.50±7.99, (p=0.003), systolic blood pressure increased from 148.67±26.36 mmHg to 155.00±28.50, (p=0.05), and diastolic blood pressure increased from 78.62±12.74 mmHg to 84.83±14.55, (p=0.036). There was a moderate but significant correlation between change in IVCe and ultra-filtrate volume. The study did not collect sufficient evidence to show significant correlation between change in IVCi and ultra-filtrate volume (Table 4).

Table 5 and 6 shows the fluid status before and after HD. According to the dry weight method, out of 30 patients 5 were hypervolemic, 23 were euvolemic and 2 were hypovolemic before dialysis and after dialysis 2 were still hypervolemic, 16 were euvolemic and 12 were hypovolemic. According to the IVC-CI, 15 were hypervolemic, 9 euvolemic, and 6 hypovolemic before dialysis. After dialysis 4 were hypervolemic, 7 euvolemic, and 19 were hypovolemic. There were significant number of patients who became hypovolemic after dialysis according to the IVC-CI.

DISCUSSION

Our results suggest that the physical exam and clinical parameters are insensitive and non-specific for determination of fluid status. Underestimation of dry weight leads to complications of hypovolemia with adverse symptoms such as dizziness, headache, and muscle cramps. In extreme cases, overaggressive

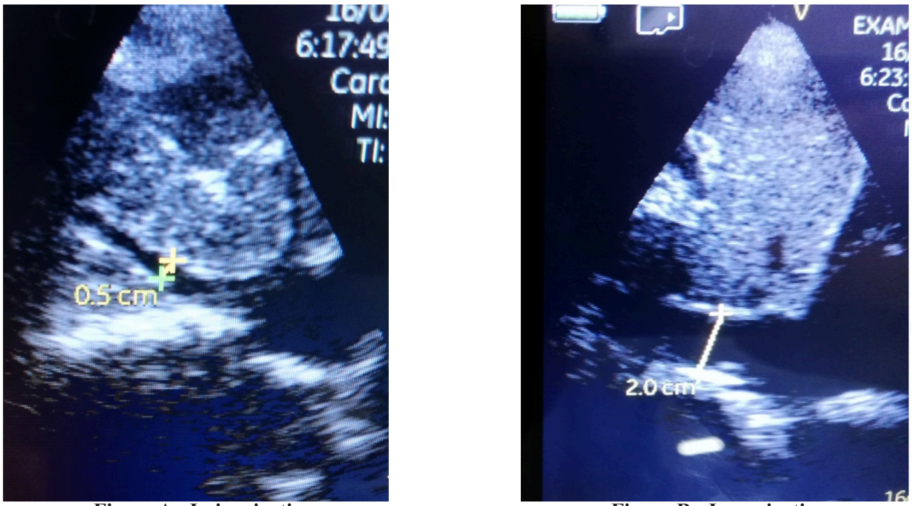

Figure A : In inspiration **Figure B : In expiration**

Figure 1: Measuring inferior vena cava using handheld ultrasound.

Table 5: Volume status before dialysis

Volume status based on weight	**Volemic status based on IVC-CI**			**Total**
	Hypervolemia	Euvolemia	Hypovolemia	
Hypervolemic	4	1	0	5
Euvolemic	11	7	5	23
Hypovolemic	0	1	1	2
Total	**15**	**9**	**6**	**30**

Table 6: Volume status after dialysis

Volemic status based on weight	**Volemic status based on IVC-CI**			**Total**
	Hypervolemia	Euvolemia	Hypovolemia	
Hypervolemic	0	1	1	2
Euvolemic	2	4	10	16
Hypovolemic	2	2	8	12
Total	**4**	**7**	**19**	**30**

ultrafiltration leads to intradialytic hypotension which endangers perfusion to vital organs. In our patients', signs and symptoms of hypovolemia in the course of dialysis occurred in twelve instances. After dialysis the patients' blood pressure is expected to decrease compared to pre-dialysis blood pressure, however, our study shows that there were significant rise of both systolic and diastolic blood pressure and heart rate. The paradoxical hypertension is the indicator of renin-angiotensin-aldosterone axis activation due to hypovolemia.[7] Overestimation of the dry weight may cause chronic fluid overload and complications such as hypertension, congestive heart failure, and pulmonary edema. Clinical parameters of hydration status are influenced by factors other than fluid status and are not always reliable. More reliable parameters such as central venous pressure (CVP)and measurement of total blood volume by radioiodinated albumin are invasive. Non-invasive methods for estimation of hydration in HD patients such as bioimpedance and levels of Atrial Natriuretic Peptide (ANP) are available but require special machines and are not very accurate.[8] 2-D ultrasound machines are readily available in most of the hospitals and can be easily used to measure IVCD in inspiration and expiration. IVCD has been shown in previous studies to reflect the intravascular volume in HD patients and to correlate well with invasive methods like measurement of CVP for estimation of fluid volume.[9]

This study has been done to measure IVCD and calculate IVC-CI to categorize the fluid status of regular hemodialysis patients. In this study, IVCe and IVCi were measured and the collapsibility indices of IVC calculated which correlated well with the amount of ultrafiltration done during hemodialysis. In our study, IVCD decreased significantly following dialysis and correlated well with the changes in weight, and IVC-CI increased significantly after ultrafiltration.

When the patients' fluid status was categorized according to the IVC-CI, 19 out of 30 patients (63.3%) were hypovolemic after dialysis. This can explain the high number of adverse symptoms suffered by the patients, such as dizziness, muscle cramps, and headache during and after hemodialysis. Hypovolemia immediately after dialysis could be the causative factor of paradoxical hypertension and increased heart rate after dialysis, both of which were significantly increased after dialysis.

Although promising, this method has several limitations. One of the obstacles is a lack of standard values for IVC-CI to suggest fluid status. In our study we have taken IVC-CI<0.40 as hypervolemic, IVC-CI>0.40 to <0.75 as euvolemic and IVC-CI>0.75 as hypovolemic. Significant inter-individual variations and presence of numerous factors which affect IVCD require large population studies in order to place the values of IVCD and IVC-CI on nomograms. Another limitation of IVC diameters as an indicator of fluid status is the fact that it mainly reflects the intravascular space. IVCD measured immediately after dialysis may not accurately represent the amount of total body water. It is recommended to measure the IVC diameters several hours following HD to achieve maximum refilling from the extravascular space.

Keeping in mind the limitations of the method, IVC diameters measured by ultrasonography may serve as an additional useful parameter in estimation of fluid status in patients treated with HD.

CONCLUSIONS

It was found that there was a significant correlation between IVCD and IVC-CI with ultrafiltrate of hemodialysis. Our findings support the applicability of IVCD measurement and IVC-CI in the estimation of fluid status in ESKD patients on regular HD. Clinical parameters of fluid status including heart rate, systolic blood pressure, and diastolic blood pressure clearly indicates in our study that a significant number of patients underwent excess ultrafiltration based on their traditional dry weight calculation. Thus, using IVC parameters before and during hemodialysis might give a better estimation of fluid status of the patient and guide the amount of ultrafiltration to be done.

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