Original Article

The Value of Inferior Vena Cava Ultrasonography Administration for Hypovolemia Detection in Patients with Acute Kidney Injury Hospitalized in Intensive Care Unit

Saeed Abbasi[1], Kourosh Nemati[2], Babak Alikiaii[2], Mahmood Saghaei[2]

[1]Department of Anesthesia and Critical Care, Anesthesiology and Critical Care Research Center, Nosocomial Infection Research Center, Isfahan University of Medical Sciences, Isfahan, Iran, [2]Department of Anesthesia and Critical Care, Anesthesiology and Critical Care Research Center, Isfahan University of Medical Sciences, Isfahan, Iran

Abstract

Background: The hypo-perfusion of the kidneys can lead to impairment in renal function and induce renal injury in case of delayed diagnosis and treatment. To date, laboratory markers are routinely used to determine the fluid volume status of the patients. The current study aims to evaluate the values of inferior vena cava (IVC) collapsibility index in hypovolemia diagnosis among critical patients admitted at the intensive care unit (ICU).

Materials and Methods: This is a cross-sectional study performed on 67 patients admitted to the ICU due to acute kidney injury from May 2018 to October 2019. Hypovolemia was assessed assessing IVC collapsibility using ultrasonography. Laboratory data, including urine osmolality, urine-plasma creatinine ratio, sodium excretion fraction and urinary sodium level were checked. Afterward, IVC collapsibility index was measured for each patient using ultrasonography and the values of this index in accordance with the mentioned criteria was evaluated. Accordingly, reciever operating curve was depicted.

Results: There was no significant asosociation between IVC collapsibility index with fractional excretion of sodium ($P = 0.69$), urine Na ($P = 0.93$) and urine osmolality ([$P = 0.09$]), while urine: Plasma creatinie ration revealed a significant association with IVC collapsibility index at cut point of 40.5% with sensitivity and specificity of 96% and 44% ($P = 0.017$, area under the curve: 0.67, 95% confidence interval: 0.551–0.804), respectively.

Conclusion: According to the findings of this study, IVC collapsibility detected via ultrasonography was not an appropriate index to figure out hypovolemia in ICU patients. Furthermore, detailed studies are recommended.

Keywords: Acute kidney injury, hypovolemia, inferior vena cava, ultrasonography

Address for correspondence: Dr. Kourosh Nemati, Department of Anesthesia and Critical Care, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran.
E-mail: knv.1353@yahoo.com
Submitted: 17-Dec-2021; **Revised:** 06-Feb-2022; **Accepted:** 07-Feb-2022; **Published:** 25-Feb-2023

Introduction

Kidney failure as a leading cause of increased hospital stay and mortality,[1] is defined as a severe reduction in kidney function categorized as acute and chronic renal failure according to the course of the disease.[2]

Acute kidney injury (AKI) occurs due to varieties of etiologies divided into three subgroups of prerenal, renal, and postrenal azotemia.[3] Prerenal azotemia is a condition known by the insufficient blood supply to the kidneys due to intravascular volume deficiency. The early and concise

Access this article online	
Quick Response Code:	**Website:** www.advbiores.net
	DOI: 10.4103/abr.abr_394_21

How to cite this article: Abbasi S, Nemati K, Alikiaii B, Saghaei M. The value of inferior vena cava ultrasonography administration for hypovolemia detection in patients with acute kidney injury hospitalized in intensive care unit. Adv Biomed Res 2023;12:38.

diagnosis of this condition in critical patients admitted at intensive care unit (ICU) is a significant challenge for the physicians, while any delay in diagnosis and treatment can cause prominent adversities such as permanent renal failure, dialysis requirement, and even death.[4]

The term response and nonresponse to volume compensation in AKI was coined due to the need for proper volume assessment and resuscitation in renal injury.[5] The overall incidence of AKI in ICU patients ranges from 20% to 50% with lower incidence seen in elective surgical patients and higher in sepsis ones. One of the most important risk factors for AKI is hypovolemia.

Accurate volume assessment is a major challenge, especially in patients with critical conditions. A history and physical examination can partially determine a patient's volume deficiency, but it is not always accurate and reliable.

To data, laboratory markers are routinely administered to diagnose prerenal azotemia.[6,7] However, these markers may be appeared when the volume status gets into critical conditions or they may be altered by the therapeutic interventions done for the patients in ICU; accordingly, a precise criterion to evaluate the volume deficiency in these patients is required. Although the paucity of knowledge is available, inferior vena cava (IVC) collapsibility degree assessment via ultrasonography has shown promising associations with intravascular volume.[8,9]

Considering the importance and prevalence of AKI in patients having a critical condition and the pivotal roles of prerenal azotemia and hypovolemia in this regard and the practical use of IVC collapsibility by ultrasound, the current study aims to predict the predictive value of IVC ultrasound in the volume deficiency diagnosis in patients admitted at the ICU in comparison with laboratory prerenal azotemia.

Materials and Methods

Study population

This is a cross-sectional study conducted on 67 known AKI cases admitted at ICU of Alzahra Hospital affiliated at Isfahan University of Medical Sciences from May 2018 to October 2019. The study protocol was approved by the Research Committee of Isfahan University of Medical Sciences and the Ethics committee has confirmed it (Ethics code: IR. MUI. MED. REC.1399.174).

The inclusion criteria were age over 18 years, admission to ICU, requiring intubation and mechanical ventilation, exposure to the leading causes of volume deficiency (such as bleeding, sepsis, metabolic disorder (hypernatremia (Na >145 mEq/L),[10] hypercalcemia (Ca >10.5 mg/dl),[11] hyperglycemia (random blood glucose >200 mg/dl)[12]), and AKI stages 1 or 2 according to the Kidney Disease: Improving Global Outcomes (KDIGO) guideline. Based on KDIGO, AKI is defined as an increase of 0.3 mg/dl in creatinine within 48 h, equal to or more than 1.5 times increase of creatinine from the baseline within 7 days or <0.5 cc/kg/h urine output for 6 h.[13]

Any previous history of renal replacement therapy, chronic kidney disease, chronic hepatic failure, pulmonary hypertension, moderate-to-severe heart failure defined as left ventricular ejection fraction <30% and contrast-induced nephropathy was determined as the study exclusion criteria.

The eligible patients were selected based on the mentioned criteria by the nonprobability sampling method.

Data collection

The patients' demographic characteristics (age and gender) were entered into the study checklist.

Mean arterial pressure (MAP) of the patients was measured using a standard cuff to assess the blood pressure. Then, MAP was calculated based on the formula:[14]

MAP= (SBP + 2DBP)/3.

Then, blood samples were extracted and the creatinine of the patients was measured. Besides, sterile random urine samples were taken to measure the parameters, including urine osmolality (≥500 mosmol/kgH_2O vs. <500 mosmol/kgH_2O), fractional excretion of sodium (FENa) (≥1% vs. <1%), urine sodium levels (≥20 mEq/L vs. <20 mEq/L), urine: plasma creatinine ratio (U/P creatinine ration) (≥40 vs. <40).[15]

According to the laboratory findings, hypovolemia was defined as at least one of the following characteristics; urinary osmolality <500, urine creatinine to plasma ratio <40, urinary sodium excretion fraction <1, and urinary sodium level <20.[15]

Ultrasonography

Ultrasound of IVC was performed by ultrasonography device (Sonosite, M-Turbo, Probe curve, 3–5MHz) in the supine position. The longitudinal view of the probe was performed at a location 2 cm from the connection of the IVC to the right atrium. In one respiratory cycle (inspiratory and expiratory) the dimensions of the IVC were recorded. The following formula was administered to assess the collapsibility of IVC.[16]

Collapsibility (%) = (Max IVCdiameter-min IVC diameter)/ max IVC diameter × 100%.

The minimum and maximum diameters of IVC are measured at expiration and inspiration, respectively.

To minimize the probable bias, all the ultrasonographies were performed by an expert abdominopelvic radiologist.

By the measurement of IVC collapsibility, the gathered data were administered to determine an appropriate cut-off of this index to diagnose hypovolemia in ICU admiited patients.

Data collection

The obtained data were entered into the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL, USA) version 23. Numerical variables were presented in mean and standard deviation (or with mean and interquartile range), whereas, the categorical ones were presented as absolute numbers and percentages. The normality of data distribution was assessed using Kolmogorov–Smirnov test. The continuous data were compared using independent *t*-test for data with normal distribution; otherwise, Mann–Whitney test was administered. Reciever operating curve was depicted to assess the value of IVC collapsibility index for hypovolemia diagnosis. The sensitivity, specificity, and area under the curve (AUC) were measured. $P < 0.05$ was defined as the level of significance.

Results

Data of 67 patients were analyzed. The study population consisted of 36 males (53.7%) and 31 females (46.3%) with the mean age of 64.59 ± 10.11 years (range: 28–85, median: 58). Our data showed that the mean arterial blood pressure was 70.52 ± 9.38 mmHg and the mean urinary sodium excretion was 0.78 ± 0.25. The sodium excretion was <1 in 54 patients (80.60%) and more than or equal to 1 in 13 patients (19.40%).

The mean urinary sodium was 88.65 ± 51.85 which was < 20 in 4 patients (6%) and more than or equal to 20 in 63 patients (94%). The mean ratio of urinary creatinine to plasma was 45.22 ± 6.50, which was ≤40 in 19 patients (28.4%) and more than 40 in 48 patients (71.60%). The mean urine osmolality was 524.77 ± 59.24, which was ≤500 in 21 patients (31.3%) and more than 500 in 46 patients (68.70%). The IVC index was <12% in 23 patients (34.30%) and more than or equal to 12% in 44 patients (65.7%). These data are indicated in Table 1.

Table 2 shows the association of IVC diameter with diverse laboratory indeces related to hypovolemia in ICU patients. There was no significant asosociation between IVC collapsibility index with FENa ($P = 0.69$), urine Na ($P = 0.93$) and urine osmolality ([$P = 0.09$]), while urine: Plasma creatinie ration revealed a significant association with IVC collapsibility index at cut point of 40.5% with sensitivity and specificity of 96% and 44% ($P = 0.017$, AUC: 0.67, 95% confidence interval: 0.551–0.804), respectively [Figure 1].

Table 1: The demographic and medical characteristics of the studied population

Parameters	Patients (67), *n* (%)
Age (years)	64.59±10.11
Sex (male/female)	
Male	36 (53.7)
Female	31 (46.3)
MAP (mmHg)	70.52±9.38
FENA (%)	
Mean	0.78±0.25
<1	54 (80.60)
≥1	13 (19.40)
NA urine (mg/dl)	
Mean	88.65±51.85
<20	4 (6)
≥20	63 (94)
Urine:plasma creatinine ration	
Mean	45.22±6.50
Cu.p <40	19 (28.4)
Cu.p ≥40	48 (71.6)
O.U (mosmol/kgH_2O)	
Mean	524.77±59.24
≤500	21 (31.3)
>500	46 (68.7)
IVC index (%)	
<12	23 (34.30)
≥12	44 (65.7)

Data are explained as mean±SD or *n* (%). MAP: Mean arterial pressure, FENA: Sodium fractional excretion, NA urine: Urine sodium, Cu.p: Creatinine urine to plasma, O.U: Urine osmolality, IVC: Inferior vena cava, SD: Standard deviation

Discussion

Decreased intravascular volume increases the risk of renal impairment; therefore, concise and early diagnosis in critical patients such as those admitted at ICU can help reduce morbidity and mortality.[17] Furthermore, the management of volume in patients with acute respiratory distress is remarkably sensitive and requires precise considerations.[18,19] Accordingly, diverse indices have been recommended among which IVC collapsibility assessment via ultrasonography as a noninvasive modality seems valuable.

In the current study, we found a direct significant association between the collapsibility index of IVC with urine: Plasma creatinine ratio. Given that at the cut point of 41.5%, this index had the sensitivity and specificity of 96% and 44%, respectively. Nevertheless, low achieved specificity questions the utility of the IVC collapsibility index for hypovolemia diagnosis. Further assessments revealed insignificant associations with other indices, including urine osmolality, urine Na and FENa. Therefore, we assume that a larger population may provide better knowledge about the generalize use of this IVC collapsibility index.

The study by Babar *et al*. Compared comparative ultrasound with FENa and urinary sodium in patients breathing independently (without a ventilator). The result is that the relationship between ultrasound and prerenal indices is significant.[20] Which is consistent with the present study, in this study, critical patients admitted to the ICU under ventilator were examined. Ultrasound in cases where urinary markers cannot be examined can help determine the volume status of patients.

The study by Stawicki *et al*. examined the collapsibility of the lower extremity with ultrasound in patients undergoing surgery and hospitalization in the ICU to assess intravascular volume in comparison with CVP measurements. Ultrasound collapsibility is a useful guide for assessing the volume of these patients[8] these results are consistent with the present study.

One of the matters about the use of IVC collapsibility for volume assessment is its association with spontaneous respiration. Given that, the IVC collapsibility index is

Table 2: Determining and comparing the man collapsibility of the inferior vena cava with laboratory criteria of prerenal azotemia based on *t*-test

	IVC diameter (mean±SD)	AUC (mean±SE)	95% CI	*P*
FENA (%)				
<1	23.50±12.34	0.530±0.074	0.385-0.674	0.69
≥1	20.68±10.48			
Urine NA (meq/lit)				
<20	24.50±12.84	0.506±0.075	0.360-0.653	0.93
≥20	22.52±11.83			
Urine:plasma creatinine ratio				
≤40	29.63±8.25	0.677±0.064	0.551-0.804	0.017
>40	19.95±11.98			
O.U (mosmol/kgH_2O)				
≤500	17.57±9.90	0.375±0.074	0.230-0.519	0.090
>500	24.72±12.02			

SE: Standard error, CI: Confidence interval, FENA: Sodium fractional excretion, NA urine: Urine sodium, O.U: Urine osmolality, IVC: Inferior vena cava, SD: Standard deviation, AUC: Area under the curve

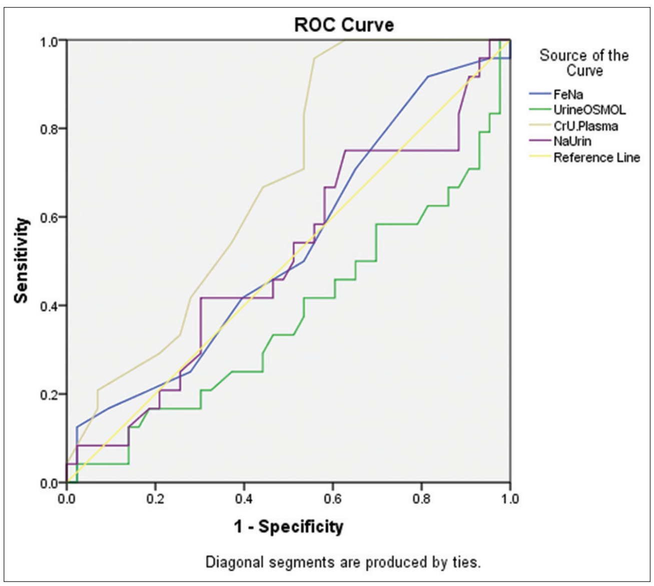

Figure 1: The ROC curve assessing IVC collapsibility index values in comparison with the other indices related to hypovolemia

calculated based on the difference of diameter that occurs between inhalation and exhalation. Airapetian *et al*. performed a study to assess this issue and presented that despite the significant values of IVC collapsibility index to evaluate the hypovolemic patients' response to hydration, the obtained association was not strong enough to generalize the outcomes. Better outcomes were achieved in patients whose systolic blood pressure was higher; however, blood pressure is not appropriate in most of the patients suffering from hypovolemia.[21]

A study by Szabó *et al*., in preoperative noncardiac patient who had spontaneous respiration, concluded that more than 50% collapse in the respiratory cycle could predict hypotension after induction of anesthesia, and as a diagnostic method for Patients are at risk for hypotension after induction of anesthesia.[22] This finding is consistent with the present study.[23]

A study was conducted by Riccardo Moretti and Pizzi on patients with subarachnoid hemorrhage who required hemodynamic monitoring and underwent ventilation and were admitted to the sedative ICU. It has investigated the collapse of IVC in predicting the response of fluid therapy in patients with subarachnoid hemorrhage. IVC ultrasound with rapid and timely diagnosis of fluid deficiency in the critical patients and timely treatment of the patient has caused an improvement in response (reduction of fluid deficiency injury) to fluid therapy in these patients.[24] These findings are consistent with the results of the present study.

Limitation

Along with the strengths, our study has significant limitations, as well. The small study population and nonhomogeneous selection of the patients are one of the most notifying limitations of this study, as the included patients were those who had AKI regardless of the etiology. Probably, more reliable outcomes can be achieved if the underlying reason for AKI was similar. Furthermore, despite all the efforts made to minimize the effects of confounding variables, some variables such as duration of hospitalization, etiology of admission, smoking status, and some potential unseen ones have been neglected. Further studies with a larger sample population and extended data related to the volume status of the patients are strongly recommended.

Conclusion

This study showed that the use of IVC ultrasound in the diagnosis of volume deficiency in ICU hospitalized patients was not statistically significant compared to laboratory criteria for prerenal thrombosis. There is more positive predictive value in prerenal azotemia criteria than IVC ultrasound to diagnose vascular volume deficiency in ICU patients. Ultrasound performed different responses compared to in laboratory parameters. Different answers can be obtained based on the disease agent or medications and serum prescribed to patients and the calculated IVC index formula. Therefore, more and more accurate ultrasound examinations are recommended in comparison with the parameters of intravascular volume deficiency.

Acknowledgments

We are grateful to Dr. Ali Safaei for his all help in the production of the current manuscript.

Financial support and sponsorship

The study was sponsored by Isfahan University of Medical Sciences.

Conflicts of interest

There are no conflicts of interest.

References

1. Challiner R, Ritchie JP, Fullwood C, Loughnan P, Hutchison AJ. Incidence and consequence of acute kidney injury in unselected emergency admissions to a large acute UK hospital trust. BMC Nephrol 2014;15:84.
2. Davison SN. Clinical pharmacology considerations in pain management in patients with advanced kidney failure. Clin J Am Soc Nephrol 2019;14:917-31.
3. Shah S, Leonard AC, Harrison K, Meganathan K, Christianson AL, Thakar CV. Mortality and recovery associated with kidney failure due to acute kidney injury. Clin J Am Soc Nephrol 2020;15:995-1006.
4. Huluka D, Ejigu A, Tilahun R, Yohannes N, Ahmed M, Tadesse Y, *et al.* Clinical Characteristics and Outcomes of Acute Kidney Injury in Adult Intensive Care Unit of Tikur Anbessa Specialized Hospital, Addis Ababa, Ethiopia. B47 CRITICAL CARE: NON-PULMONARY CRITICAL CARE: American Thoracic Society; 2020. p. A 3559.
5. Lafrance JP, Miller DR. Acute kidney injury associates with increased long-term mortality. J Am Soc Nephrol 2010;21:345-52.
6. Umbrello M, Formenti P, Chiumello D. Urine electrolytes in the Intensive Care Unit: From pathophysiology to clinical practice. Anesth Analg 2020;131:1456-70.
7. Villeneuve PM, Bagshaw SM. Assessment of urine biochemistry. In: Critical Care Nephrology. Ch. 55. Elsivier; 2019. p. 323-328.el.
8. Stawicki SP, Braslow BM, Panebianco NL, Kirkpatrick JN, Gracias VH, Hayden GE, *et al.* Intensivist use of hand-carried ultrasonography to measure IVC collapsibility in estimating intravascular volume status: Correlations with CVP. J Am Coll Surg 2009;209:55-61.
9. Kaptein MJ, Kaptein EM. Inferior vena cava collapsibility index: Clinical validation and application for assessment of relative intravascular volume. Adv Chronic Kidney Dis 2021;28:218-26.
10. Muhsin SA, Mount DB. Diagnosis and treatment of hypernatremia. Best Pract Res Clin Endocrinol Metab 2016;30:189-203.
11. Sadiq NM, Naganathan S, Badireddy M. Hypercalcemia. In: StatPearls Publishing LCC; 2020.
12. Moore PK, Hsu RK, Liu KD. Management of acute kidney injury: Core curriculum 2018. Am J Kidney Dis 2018;72:136-48.
13. Kellum JA, Lameire N, KDIGO AKI Guideline Work Group. Diagnosis, evaluation, and management of acute kidney injury: A KDIGO summary (Part 1). Crit Care 2013;17:204.
14. DeMers D, Wachs D. Physiology, mean arterial pressure. In: StatPearls Publishing LCC; 2020.
15. Waldrop JE. Urinary electrolytes, solutes, and osmolality. Vet Clin North Am Small Anim Pract 2008;38:503-12, ix.
16. Iturbide I, Santiago M, Henain F, Golab K, Tentoni M, Fuentes S. Ultrasound evaluation of the inferior vena cava in hemodynamically unstable patients. Rev Argent Radiol 2017;81:209-13.
17. Hicks P, Cooper D, Webb S, Myburgh J, Seppelt I, Peake S, *et al*. The Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock: 2008. An Assessment by the Australian and New Zealand Intensive Care Society. SAGE Publications Sage UK: London, England; 2008.
18. Alsous F, Khamiees M, DeGirolamo A, Amoateng-Adjepong Y, Manthous CA. Negative fluid balance predicts survival in patients with septic shock: A retrospective pilot study. Chest 2000;117:1749-54.
19. Wiedemann H, Wheeler A, Bernard G. Comparison of two fluid-management strategies in acute lung injury. J Vasc Surg 2006;44:909.
20. Babar F, Singh G, Noor M, Sabath B. Retrospective analysis of inferior vena cava collapsibility with point of care ultrasound and urine sodium and FENa in patients with early stage acute kidney injury. J Community Hosp Intern Med Perspect 2017;7:296-9.
21. Airapetian N, Maizel J, Alyamani O, Mahjoub Y, Lorne E, Levrard M, *et al.* Does inferior vena cava respiratory variability predict fluid responsiveness in spontaneously breathing patients? Crit Care 2015;19:400.
22. Szabó M, Bozó A, Darvas K, Horváth A, Iványi ZD. Role of inferior vena cava collapsibility index in the prediction of hypotension associated with general anesthesia: An observational study. BMC Anesthesiol 2019;19:139.
23. Sobczyk D, Nycz K, Andruszkiewicz P, Wierzbicki K, Stapor M. Ultrasonographic caval indices do not significantly contribute to predicting fluid responsiveness immediately after coronary artery bypass grafting when compared to passive leg raising. Cardiovasc Ultrasound 2016;14:23.
24. Moretti R, Pizzi B. Inferior vena cava distensibility as a predictor of fluid responsiveness in patients with subarachnoid hemorrhage. Neurocrit Care 2010;13:3-9.