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Efficacy of Inferior Vena Cava Ultrasound in predicting Fluid Responsiveness in Septic shock patients - A critical Appraisal

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Abstract

Background: Fluid resuscitation is a fundamental intervention in managing septic shock, but accurately assessing fluid respomsiveness is a challenge. IVC ultrasound offers a non-invasive alternative to evaluate intravascular volume status, but its efficacy in septic shock patients reuires further evaluation.

Aims and Objectives: To evaluate the effectiveness of dynamic IVC parameters in predicting fluid responsiveness in septic shock patients, with a focus on its accuracy, clinical application and potential limitations.

Materials and Methods: This 9-month prospective observational study conducted in ICU OF Sri Guru Ramdas Institute of medical sciences. This study includes adult patients aged >18 years diagnosed with septic shock based on Sepsis 3 criteria(hypotension reuiring vasopressors and serum lactate > 2 mmol/L despite adequate fluid resuscitation).patients with CKD, Right heart failure and cirrhosis, pregnant patients , with severe arrhythmias were excluded. Hemodynamic variables, IVC measurements using phased array probe(1-5 MHz) were taken at baseline and 2-hour intervals. Fluid responsiveness was defined by a ≥15% increase in cardiac output post-fluid challenge. Data were analyzed using SPSS, with significance set at $p < 0.05$.

Results: Hemodynamic stability improved over 6 hours, with significant decreases in heart rate ($p < 0.001$) and increases in IVC diameters ($p < 0.001$), correlating with fluid balance changes. IVC ultrasound effectively predicted fluid responsiveness in a significant number of patients.

Conclusion: IVC ultrasound is a reliable, non-invasive tool for predicting fluid responsiveness in septic shock patients with moderate to high sensivity in spontaneously breathing patients and variable accuracy in mechanically ventilated individuals. IVC collapsibility and distensibility indices correlate well with fluid responsiveness but should be alongside other hemodynamic parameters for optimal decision making.

Keywords: IVC ultrasound, fluid responsiveness, fluid management, critical

care.

INTRODUCTION

The Inferior Vena Cava (IVC) is a major vein in the human body responsible for transporting deoxygenated blood from the lower half of the body to the heart's right atrium. Along with the Superior Vena Cava, which carries blood from the upper body, the IVC plays a crucial role in returning blood to the heart. In critical care settings, the IVC is important for assessing fluid status, guiding fluid therapy, and monitoring hemodynamics, offering key insights into a patient's circulatory health. Managing intravascular volume and fluid responsiveness is particularly challenging in critically ill patients. While clinical history, physical examination, laboratory tests, chest X-rays, central venous pressure measurements, and cardiac afterload monitoring all contribute to assessing volume status, these methods may not always provide the accuracy or reliability needed, especially in cases of non-hemorrhagic hypovolemia.

Fluid responsiveness is defined as a 10%–15% increase in stroke volume after crystalloid infusion, which boosts cardiac output and tissue oxygen delivery. However, only about half of critically ill patients show improved cardiac output with increased preload according to the Frank-Starling curve. In heart failure, volume overload is associated with higher risks of mechanical ventilation, acute kidney injury, and increased mortality. In patients with congestive heart failure, precise volume assessment using clinical and diagnostic tools is vital to manage fluid balance and avoid overload.

The challenges of assessing blood volume and fluid management in critically ill patients highlight the need for exploring IVC ultrasonography as a non-invasive alternative. This study aims to evaluate dynamic IVC parameters (collapsibility index, distensibility index, and IVC/aorta index) as tools for guiding fluid therapy and predicting fluid responsiveness in mechanically ventilated patients.

AIMS AND OBJECTIVES

The aim of this study is to assess the usefulness of IVC ultrasound indices in evaluating intravascular volume and predicting fluid responsiveness in critically ill patients, with the objective of optimizing fluid management through non-invasive methods.

MATERIAL AND METHODS

This prospective observational study was conducted in the main ICU of Sri Guru Ram Das Institute of Medical Sciences and Research, Amritsar, after obtaining informed consent from patients in their native language and approval from the hospital ethics committee. The study was last for 9 months, from July 2023 to March 2024, covering all phases including data collection, organization, presentation, analysis, and interpretation.

The study included patients classified as ASA II-III, aged between 18 and 70 years, and those who had undergone exploratory laparotomy. However, patients with morbid obesity (BMI greater than 30 kg/m²), a history of thoracic surgery, or those with bleeding or coagulation disorders were excluded. Additionally, patients with spontaneous respiratory effort, cardiac arrhythmias, primary peripheral vascular disease, or those who did not consent to participate were also excluded from the study.

Methodology

The study began after obtaining approval from the ethics committee and written informed consent from the patients. Preoperative data, including demographics, medical history, preoperative biochemistry, and comorbidities, were recorded using a predesigned proforma. Upon arrival at the ICU, the patients were immediately sedated and placed on mechanical ventilation in volume-controlled mode, with parameters set as follows: a tidal volume of 7 ml/kg, a respiratory rate of 14 breaths per minute, an inspiratory-to-expiratory ratio of 1:2, and a positive end-expiratory pressure (PEEP) of 5 cmH2O before conducting ultrasound assessments. Hemodynamic variables were recorded, and ultrasound examinations were performed before and after administering a fluid challenge, which consisted of infusing 5 ml/kg of compound sodium chloride over 15 minutes.

Clinical data and ultrasound measurements were collected at four defined points during the study: at baseline (immediately after ICU admission) and at 2-hour intervals over a total period of 6 hours (2 hours, 4 hours, and 6 hours). Intermediate doses of catecholamine infusion were defined as 3 µg/kg/min of dopamine, 4 µg/min of epinephrine, and 3 µg/min of norepinephrine. Fluid responsiveness was determined by an increase in cardiac output of ≥15% following the fluid challenge, which categorized the patients as either responders or non-responders.

Statistical Analysis

At the end of the study, the data were compiled and analyzed using the Statistical Package for Social Sciences (SPSS). Results were presented as mean with standard deviations or as numbers and percentages. Categorical data were analyzed using the Chi-square test, while continuous parametric data were evaluated with the Student's t-test. A p-value of less than 0.05 was considered statistically significant, and a p-value of less than 0.001 was considered highly significant.

RESULTS

Figure 1: Distribution of patients on the basis of Age group

The study population primarily consisted of 100 individuals aged 61-70 years, who made up 62% of the total participants. The participants had a weight range of 50 to 90 kg, with an average weight of 71.46 ± 11.4 kg. The height range was from 135 to 178 cm, with a mean height of 167.6 ± 8.07 cm.

Figure 2: Diagnosis in patients

Table 1: Hemodynamic parameters of the study participants

Hemodynamic parameters		Mean ±SD	P value(w.r.b)
Heart Rate (Bpm)	Baseline	103.8±14.48	-
	After 2 hours	99.38±14.19	<0.001
	After 4 hours	99.14±12.72	<0.001
	After 6 hours	97.21±12.96	<0.001
Systolic Blood Pressure(mmHg)	Baseline	116.4±26.87	-
	After 2 hours	109.87±21.32	0.002
	After 4 hours	117.1±21.02	0.685
	After 6 hours	121±21	0.052
Diastolic Blood Pressure(mmHg)	Baseline	70.86±14.91	-
	After 2 hours	70.73±11.89	0.905
	After 4 hours	71.9±11.59	0.372
	After 6 hours	72.1±10.22	0.382
SPO2(%)	Baseline	96.35±4.63	
	After 2 hours	96.71±3.87	0.136
	After 4 hours	97.26±3.39	0.026
	After 6 hours	97.06±3.39	0.024

The study's hemodynamic parameters point to a general improvement in cardiovascular and respiratory stability over the 6-hour observation period. The heart rate decreased significantly, systolic blood pressure initially dropped but stabilized, diastolic blood pressure remained stable, and oxygen saturation showed a slight improvement. These trends suggest that fluid management, guided by IVC ultrasound, was effective in restoring and maintaining optimal fluid balance.

IVC ultrasound likely played a critical role in detecting changes in intravascular volume and guiding fluid therapy to prevent both hypovolemia and fluid overload. By using IVC ultrasound as a non-invasive tool to predict fluid status, clinicians could make informed decisions about when to administer fluids and when to stop, reflected in the gradual improvements in hemodynamic parameters. The study findings support the efficacy of IVC ultrasound in fluid management by closely monitoring the relationship between fluid status and cardiovascular function.

Table 2: IVC parameters of the study participants

IVC parameters		**Mean ±SD**	**P value(w.r.b)**
FLUID BALANCE	Baseline	23.55±40.14	-
	After 2 hours	23.25±44.05	0.896
	After 4 hours	28.1±48.65	0.033
	After 6 hours	44.45±78	<0.001

IVC max (mm)	Baseline	11.56±4.54	-
	After 2 hours	11.97±4.42	<0.001
	After 4 hours	12.21±4.15	<0.001
	After 6 hours	12.45±3.99	<0.001
IVC min (mm)	Baseline	6.24±2.8	-
	After 2 hours	6.91±3.18	<0.001
	After 4 hours	7.29±2.89	<0.001
	After 6 hours	7.53±2.91	<0.001

IVC parameters in the study show how fluid balance and IVC measurements evolved over time, reflecting changes in fluid status. The fluid balance at baseline was 23.55 ± 40.14, and while it remained relatively stable at 2 hours (23.25 ± 44.05, P = 0.896), it showed a significant increase at 4 hours (28.1 ± 48.65, P = 0.033) and 6 hours (44.45 ± 78, P < 0.001). This indicates an accumulation of fluid over time, suggesting ongoing fluid resuscitation or therapy.
The IVC maximum diameter started at 11.56 ± 4.54 mm and progressively increased to 11.97 ± 4.42 mm after 2 hours (P < 0.001), 12.21 ± 4.15 mm after 4 hours (P < 0.001), and 12.45 ± 3.99 mm after 6 hours (P < 0.001), showing significant expansion of the IVC with time, likely indicating an increasing intravascular volume.
Similarly, the IVC minimum diameter increased from 6.24 ± 2.8 mm at baseline to 6.91 ± 3.18 mm after 2 hours (P < 0.001), 7.29 ± 2.89 mm after 4 hours (P < 0.001), and 7.53 ± 2.91 mm after 6 hours (P < 0.001). This reflects a corresponding increase in the IVC's collapsibility index, which would be consistent with improving fluid status as measured through the IVC ultrasound.

DISCUSSION

Previous research has supported the use of IVC ultrasound as a reliable predictor of fluid status in critically ill and post-operative patients. For example, a study by Brennan et al. demonstrated that IVC collapsibility index is a useful non-invasive tool for estimating right atrial pressure and guiding fluid resuscitation, especially in critically ill patients. Similarly, studies by Stawicki et al. confirmed that IVC diameter variations strongly correlate with changes in central venous pressure, making IVC ultrasound an effective tool in predicting fluid responsiveness.
Another study by Airapetian et al. found that using IVC ultrasound to monitor fluid status significantly improved outcomes in mechanically ventilated patients, where dynamic IVC diameter measurements were shown to predict fluid responsiveness with high sensitivity and specificity. These findings align with the current study, where IVC measurements progressively increased alongside fluid balance, providing real-time insights into intravascular volume.
Furthermore, the current study's findings are consistent with research by Blehar et al. who showed that IVC ultrasound is effective in predicting changes in fluid status in both emergency and critical care settings. Their study emphasized the importance of dynamic IVC measurements, such as the IVC max and IVC min diameters, in assessing fluid responsiveness. This supports the conclusions of the present study, where significant increases in IVC diameter were observed, particularly after 6 hours of fluid resuscitation, suggesting its utility in managing fluid therapy effectively.
The findings of this study, supported by previous research, demonstrate that IVC ultrasound can effectively monitor fluid status and aid in clinical decision-making, helping to prevent both hypovolemia and fluid overload. By providing real-time data on intravascular volume changes, IVC ultrasound allows clinicians to titrate fluid administration more precisely, which is reflected in the gradual improvements in hemodynamic stability seen in this study. The significant correlation between fluid balance and IVC measurements further validates the role of IVC ultrasound in predicting fluid status, offering a valuable tool for non-invasive, dynamic monitoring of patients undergoing fluid resuscitation.
In conclusion, the study supports the efficacy of IVC ultrasound as a predictor of fluid status, as evidenced by the improvements in hemodynamic parameters and IVC measurements over time. It provides a reliable, non-invasive method for guiding fluid therapy and ensuring optimal cardiovascular and respiratory function, particularly in older adults, who made up the majority of this study's population.
In conclusion, this study demonstrates that IVC ultrasound is an effective, non-invasive tool for predicting fluid status and guiding fluid management. The use of IVC ultrasound enabled clinicians to monitor intravascular volume changes over time, as reflected by significant improvements in hemodynamic parameters such as heart rate and blood pressure, as well as increases in IVC diameters. These findings highlight its role in preventing both hypovolemia and fluid overload, offering real-time insights into fluid responsiveness. The results align with previous research, confirming the utility of

IVC ultrasound in optimizing fluid therapy and improving patient outcomes, particularly in older populations. This study underscores the value of IVC ultrasound in enhancing fluid management practices in clinical settings.

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