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A Prospective Interventional Study to See the Extent of Respiratory Variation in IVC Diameter In Clinically Hypovolemic and Mechanically Ventilated Patients as an Index of Fluid Responsiveness

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ABSTRACT

Background: Fluid therapy remains a cornerstone in the management of critically ill patients to maintain hemodynamic stability and adequate tissue perfusion. However, excessive fluid administration can be harmful, making accurate assessment of fluid responsiveness essential. Ultrasonographic measurement of the inferior vena cava (IVC) distensibility index (diIVC) offers a non-invasive alternative to traditional invasive methods such as central venous pressure (CVP).
Aims and Objectives: The primary objective of this study was to assess the IVC distensibility index (diIVC) in mechanically ventilated patients as an indicator of fluid responsiveness. The secondary objective was to compare changes in diIVC and CVP before and after fluid challenge.
Methods: This prospective interventional study was conducted in the General Intensive Care Unit (GICU) of the Department of Anaesthesia, in a tertiary care centre, over nine months. Fifty adult mechanically ventilated hypovolemic patients were enrolled. diIVC and CVP were recorded before, immediately after, and 15 minutes following a 10 ml/kg crystalloid fluid challenge. Statistical analysis was performed using SPSS version 25, and correlations were analyzed using Pearson's coefficient.
Results: A significant moderate negative correlation was observed between diIVC and CVP before fluid administration ($r = -0.41$, $p = 0.003$). Significant correlations persisted between diIVC measured immediately and 15 minutes post-infusion with pre-fluid CVP ($r = -0.406$ and -0.37, respectively). However, correlations between diIVC and post-fluid CVP values were weak and statistically non-significant. Responders demonstrated significantly higher baseline diIVC (33.21 ± 9.15%) compared to non-responders (15.63 ± 2.21%), while CVP was lower in responders (4.67 ± 1.54 cm H_2O vs. 5.91 ± 1.76 cm H_2O).
Conclusion: The IVC distensibility index serves as a reliable, non-invasive marker for predicting fluid responsiveness in mechanically ventilated patients, with better correlation than static measures such as CVP. diIVC assessment can guide fluid resuscitation and prevent fluid overload in critically ill patients.

Keywords: *Respiratory, Variation, IVC Diameter, Hypovolemic, Mechanically.*

INTRODUCTION

Fluid therapy is a cornerstone in the management of critically ill patients, playing a vital role in optimizing hemodynamic stability, maintaining tissue perfusion, and improving overall outcomes. Hemodynamic instability in such patients often results from sepsis, trauma, or major surgery, all of which can lead to hypovolemia and impaired organ perfusion. Judicious administration of intravenous fluids, including crystalloids or colloids, helps restore intravascular volume, cardiac output, and mean arterial pressure, thereby supporting oxygen delivery and organ function. In conditions like septic shock, early and adequate fluid resuscitation remains a key component of initial management to reverse hypotension and prevent multiorgan failure. However, excessive fluid administration can lead to overload and worsen outcomes, emphasizing the need for reliable methods to guide fluid therapy.[1,2]

Ultrasound has emerged as a simple, non-invasive, and effective tool for assessing fluid status and guiding resuscitation. Among various ultrasonographic parameters, the inferior vena cava (IVC) offers a reliable window into venous return and volume status. The IVC is a thin-walled, highly collapsible vessel that reflects changes in intrathoracic pressure, circulating volume, and right heart function. During respiration, variations in IVC diameter can be used to calculate indices that predict fluid responsiveness. In spontaneously breathing patients, inspiratory collapse of the IVC is quantified as the IVC collapsibility index, while in mechanically ventilated patients, the IVC distensibility index (diIVC) reflects the inspiratory distension due to positive pressure ventilation.[3,4]

Given its simplicity, repeatability, and non-invasive nature, IVC ultrasonography provides a promising alternative to invasive or expensive hemodynamic monitoring techniques. Therefore, the present study was designed to evaluate the effectiveness of the IVC distensibility index as a reliable parameter to guide fluid therapy in mechanically ventilated critically ill patients.

MATERIALS AND METHODS

After obtaining approval from the Institutional Research and Ethics Committee, the study was registered with the Clinical Trials Registry of India (CTRI/2024/06/069043). Written informed consent was obtained from the parent or guardian of each patient before inclusion. This was a prospective interventional study conducted over a period of nine months in the General Intensive Care Unit (GICU) of the Department of Anesthesia, in a tertiary care centre. The aim of the present study was to assess the extent of respiratory variation in the inferior vena cava (IVC) diameter in clinically hypovolemic and mechanically ventilated patients as an index of fluid responsiveness. The primary objective was to evaluate the IVC distensibility index (diIVC) in mechanically ventilated patients, while the secondary objective was to compare the changes in the IVC distensibility index (diIVC) and central venous pressure (CVP) following a fluid challenge.

The study included 50 mechanically ventilated adult patients aged above 18 years and weighing between 50–80 kg who were admitted to the ICU with clinical evidence of hypovolemia. All patients were ventilated with a tidal volume of 8–10 ml/kg, a respiratory rate of 10–15 cycles per minute, and a positive end-expiratory pressure (PEEP) of 4–6 cm H_2O. Hypovolemia was defined by one or more of the following parameters: mean arterial pressure (MAP) < 65 mmHg, urine output < 30 ml/hour, and central venous pressure (CVP) < 8 cm H_2O.

Patients were excluded if they or their guardians refused participation, or if they had right ventricular failure, significant cardiac disease with an ejection fraction < 40%, raised intra-abdominal pressure, pregnancy, morbid obesity, or abdominal wounds or dressings preventing ultrasound assessment.

Once the diagnosis of hypovolemia was established, the distensibility index of the inferior vena cava (dIVC) was measured using ultrasonography. Patients were placed in the supine position, and a curvilinear probe was positioned in the subxiphoid region to obtain a long-axis view of the IVC. The minimum and maximum anteroposterior diameters were recorded approximately 3 cm caudal to the right atrial border or 1 cm distal to the hepatic vein inlet. The measurements were taken in M-mode with the cursor placed perpendicular to the IVC.

The dIVC was calculated using the following formula:

$$\text{dIVC} = \frac{\text{Max. IVC diameter} - \text{Min. IVC diameter}}{\text{Min. IVC diameter during inspiration}} \times 100$$

Heart rate, arterial pressure, CVP, SpO_2, and signs of heart failure were recorded before fluid administration, immediately after (0 minutes), and 15 minutes following a fluid challenge. CVP was measured via a central venous catheter inserted in the internal jugular vein. All patients received 10 ml/kg of intravenous crystalloid solution over 15 minutes, and were closely observed for any adverse effects such as oxygen desaturation or signs of right heart failure.

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 25.0 (Chicago, USA). Continuous variables were expressed as mean ± standard deviation (SD), and statistical analysis was performed using paired and independent *t*-tests where appropriate. A *p*-value of less than 0.05 was considered statistically significant.

OBSERVATIONS AND RESULTS

A significant moderate negative correlation was observed between diIVC and CVP before fluid administration (r = –0.41), indicating that lower CVP values were associated with higher diIVC values. Similar significant negative correlations were found between diIVC at 0 and 15 minutes with pre-fluid CVP (r = –0.406 and –0.37, respectively). However, correlations between diIVC and CVP measured immediately and 15 minutes after fluid administration were weak and statistically non-significant.

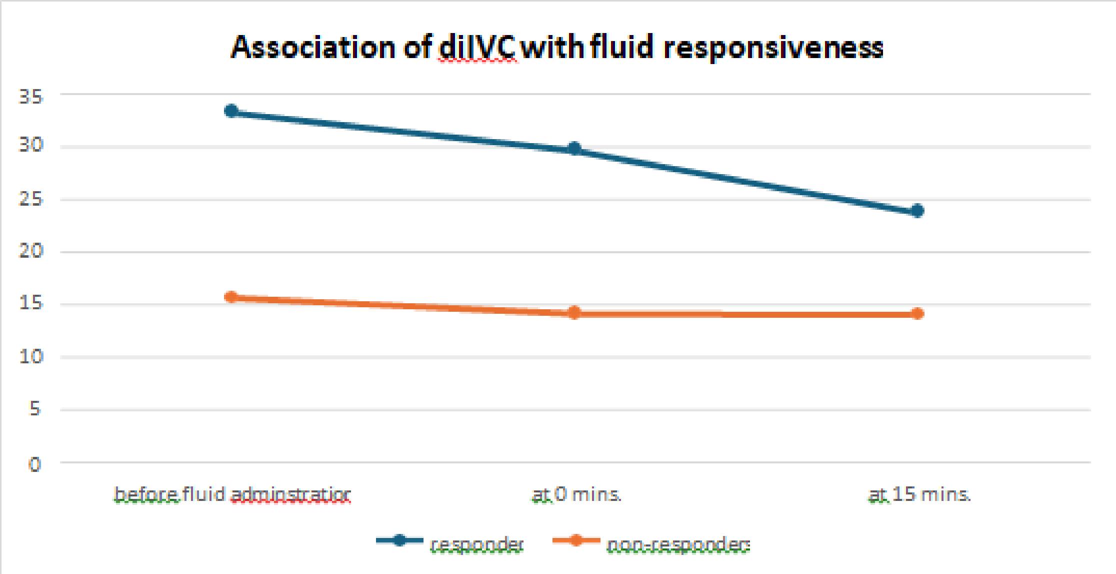

Figure 1: association of diIVC with fluid responsiveness

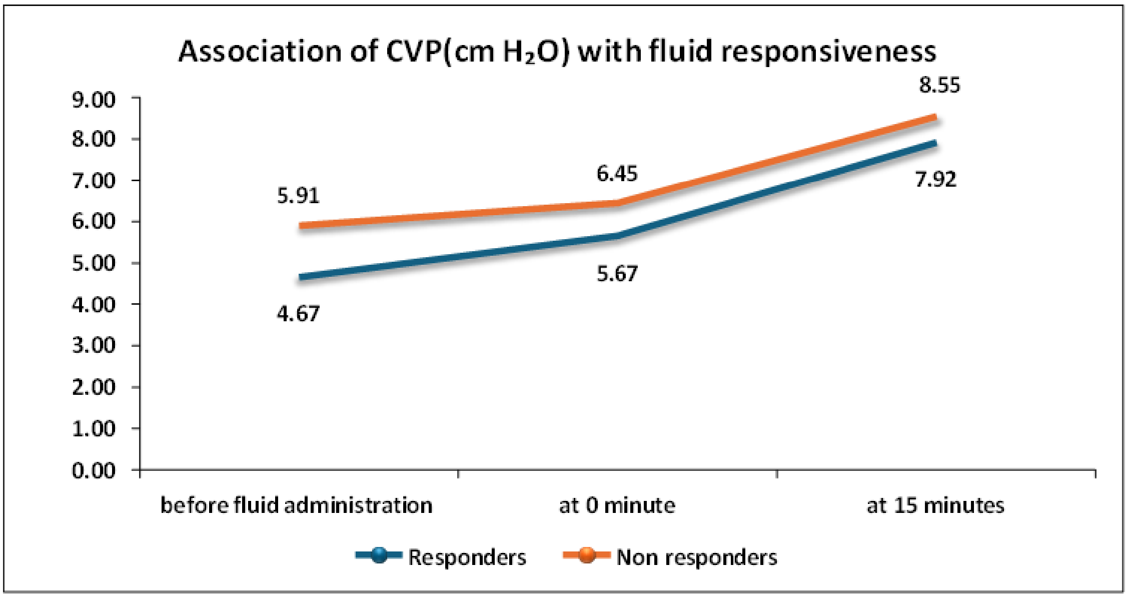

Figure 2: association of CVP with fluid responsiveness

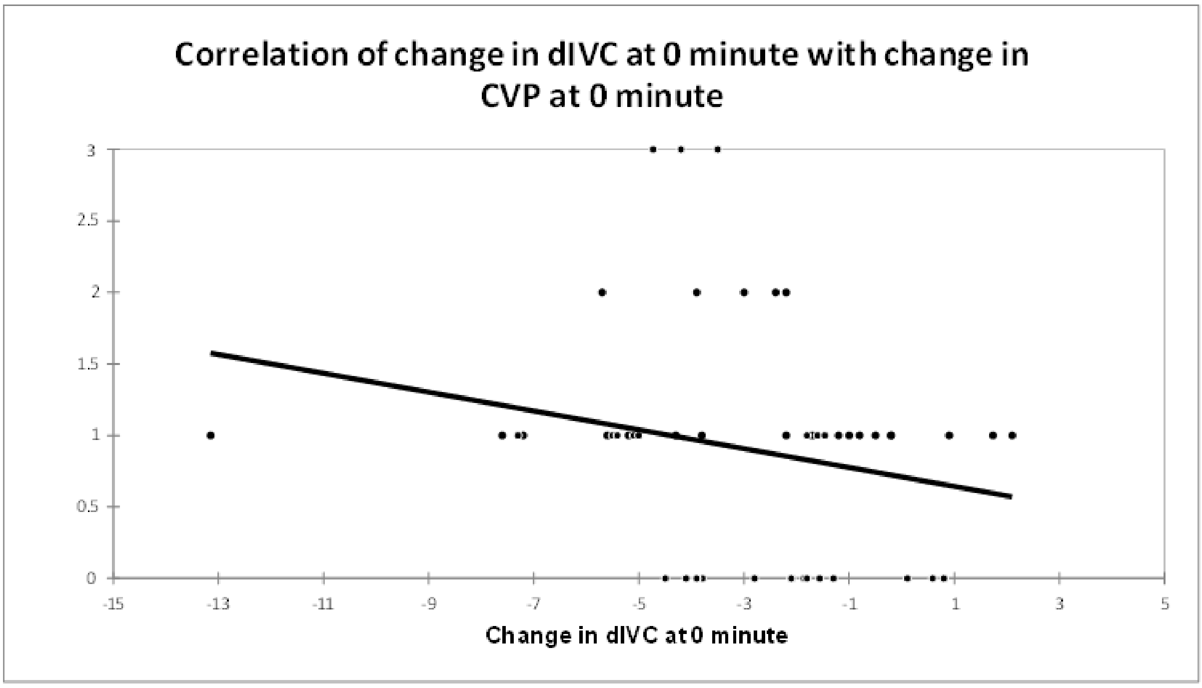

Figure 3: correlation of change dIVC at 0 minute with change in CVP at 0 minute

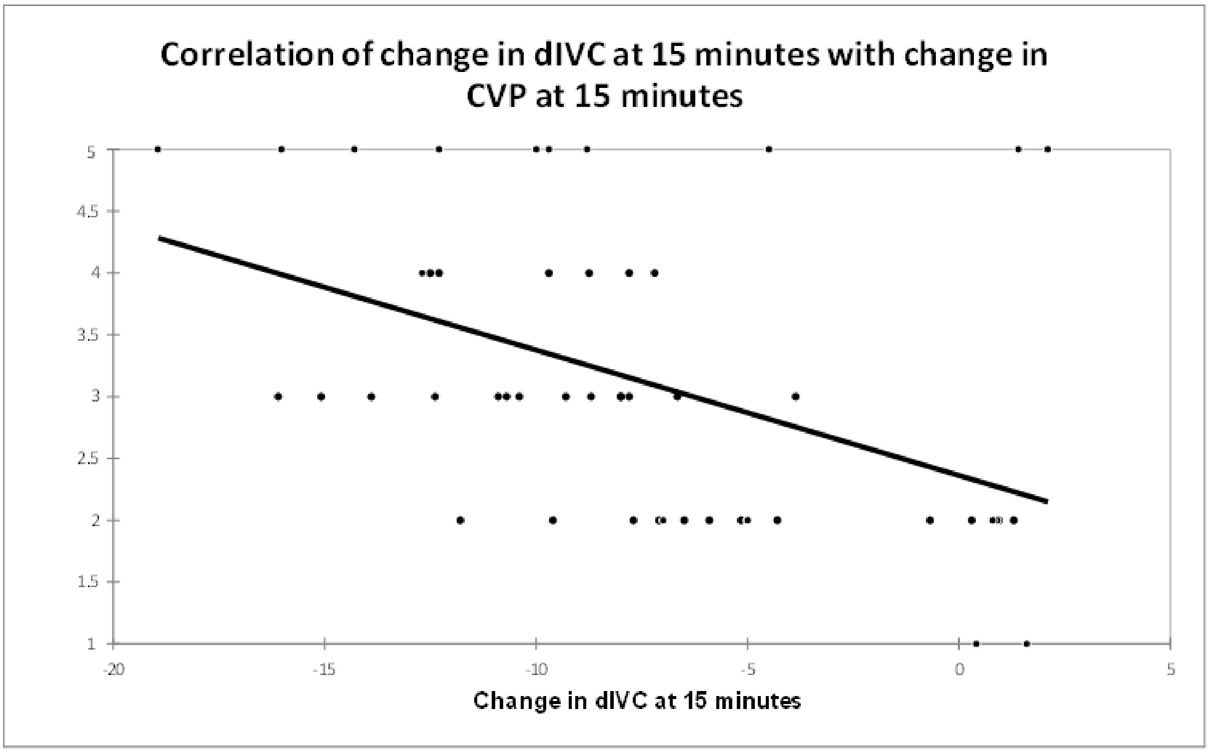

Figure 4: correlation of change dIVC at 15 minutes with change in CVP at 15 minutes

DISCUSSION

Optimal management of critically ill patients relies on early recognition and appropriate treatment of hypovolemia. Fluid therapy plays a central role in maintaining hemodynamic stability, tissue perfusion, and organ function. Both inadequate and excessive fluid resuscitation carry significant risks—under-resuscitation can result in hypoperfusion, metabolic derangements, and organ failure, whereas over-resuscitation may lead to pulmonary edema, cardiac overload, coagulopathy, and increased mortality. Therefore, accurate assessment of volume status and prediction of fluid responsiveness are essential components of critical care management.[5,6]

Hypovolemia can be broadly described as a reduction in circulating blood volume that leads to tissue hypoperfusion and improves with volume replacement. Clinically, there are no direct methods to quantify blood volume, and thus hypovolemia is often pragmatically defined as a state in which stroke volume or cardiac output increases following a fluid challenge—commonly referred to as fluid responsiveness. Importantly, studies have shown that only about half of patients respond to fluid administration with a meaningful improvement in cardiac output, emphasizing the need for reliable predictors before initiating fluid therapy. Traditionally, static parameters such as central venous pressure (CVP), pulmonary artery occlusion pressure, and end-diastolic volume have been used to estimate volume status. However, these indices correlate poorly with fluid responsiveness. Dynamic parameters that assess variations in preload during the respiratory cycle—such as pulse pressure variation (PPV), stroke volume variation (SVV), and inferior vena cava distensibility index (diIVC)—have demonstrated superior predictive accuracy, particularly in mechanically ventilated patients. Among these, ultrasonographic evaluation of the IVC has gained prominence due to its non-invasive, inexpensive, and bedside applicability.[7,8]

Several studies have evaluated the utility of IVC distensibility in predicting fluid responsiveness. Barbier et al.[9] (2004) demonstrated that a diIVC value above 18% predicted fluid responsiveness with 90% sensitivity and 90% specificity in mechanically ventilated patients with septic shock. Kaur et al.[10] (2020) compared SVV and diIVC in 67 hypotensive, mechanically ventilated patients and reported that a diIVC threshold of 17.86% predicted responsiveness with 68.9% sensitivity and 72.7% specificity. Similarly, Akyıldız et al.[11] (2021) found that diIVC had superior predictive value compared to PPV in critically ill children, with 90.5% sensitivity and 94.7% specificity. Based on these findings, our study employed a cut-off value of diIVC >18% to define fluid responsiveness. Muller et al.[12] (2012) further reported that the predictive reliability of IVC distensibility diminishes in older patients, likely due to reduced venous compliance and age-related cardiovascular changes. Nevertheless, in general ICU populations, IVC-derived indices remain among the most reliable non-invasive predictors of preload responsiveness.

In our study, 50 mechanically ventilated critically ill patients were evaluated for fluid responsiveness using diIVC before and after a fluid challenge. The mean age of participants was 43.88 ± 14.6 years, with most subjects belonging to the 18–40-year group. No significant association was observed between age and fluid responsiveness, consistent with previous findings by Mathews et al.[13] (2023), who reported no correlation between IVC collapsibility and age or sex. Gender distribution was equal (25 males and 25 females), and no significant sex-related differences were identified, which aligns with the meta-analysis by Pasquero et al.[14] (2016) showing that while absolute IVC diameters may differ between sexes, collapsibility indices remain comparable.

Fluid administration in our study produced a statistically significant increase in mean arterial pressure (MAP) at both 0 minutes ($p = 0.011$) and 15 minutes ($p < 0.001$) post-infusion. Notably, MAP at 15 minutes was significantly higher among responders (63.95 ± 2.94 mmHg) compared to non-responders (59.82 ± 2.89 mmHg; $p = 0.0001$). This finding mirrors the results of Ma Qian et al.[15] (2017), who observed that higher baseline diIVC and lower MAP predicted greater responsiveness to fluids in postoperative ICU patients. In addition, we observed a significant decrease in heart rate 15 minutes after fluid administration ($p = 0.004$), reflecting improved circulatory filling and attenuation of compensatory tachycardia. Although CVP showed a significant difference between responders and non-responders before fluid administration ($p = 0.027$), it did not correlate with responsiveness following the fluid challenge. This finding supports the meta-analysis by Marik et al.[16] (2013), which concluded that CVP is an unreliable guide for fluid resuscitation due to its dependence on multiple variables, including right heart function, venous compliance, and patient positioning.

In our study, mean diIVC values decreased from 29.98% at baseline to 27.10% immediately after fluid administration and 22.51% at 15 minutes. Responders consistently exhibited higher baseline diIVC values (33.21 ± 9.15%) compared with non-responders, with significant reductions following volume expansion. These observations are in close agreement with Barbier et al.[9] (2004), who reported that responders had higher baseline diIVC values (40 ± 24%) that declined significantly after fluid therapy. The observed decline in diIVC following fluid administration indicates a reduction in IVC distensibility as venous return and right atrial filling improve, reflecting restoration of intravascular volume. This reinforces the utility of IVC ultrasonography as a dynamic, non-invasive indicator of fluid responsiveness in mechanically ventilated patients.

In our cohort, 11 patients (22%) were classified as non-responders. Fluid non-responsiveness is an important clinical phenomenon, reflecting a state where further volume expansion fails to augment cardiac output. Contributing factors may include impaired cardiac compliance, decreased venous tone, increased intrathoracic pressure, vascular leakage, or pre-existing cardiac dysfunction. Recognizing these patients early is crucial to prevent unnecessary fluid loading and its associated complications, including pulmonary edema and organ congestion. Our findings support the growing body of evidence favoring ultrasound-derived indices, particularly IVC distensibility, as reliable tools for guiding fluid resuscitation in critically ill patients. Compared to invasive techniques, ultrasonographic assessment offers simplicity, safety, and repeatability at the bedside. The absence of significant correlations with age or gender in our cohort further enhances its applicability across diverse patient populations. However, interpretation should always be individualized, considering confounding factors such as elevated intra-abdominal pressure, altered thoracic compliance, and right heart dysfunction.

This study was limited by its relatively small sample size and single-center design, which may restrict the generalizability of findings. Variations in ventilatory parameters, intra-abdominal pressures, and operator dependence of ultrasonographic measurements may also influence results. Future multicentric studies with larger populations are needed to establish standardized cut-off values and to assess diIVC performance across different clinical scenarios, including spontaneous breathing and varying modes of ventilation.

The present study reinforces that the IVC distensibility index is a valuable, non-invasive predictor of fluid responsiveness in mechanically ventilated critically ill patients. A diIVC cut-off value greater than 18% demonstrated good diagnostic performance in identifying responders. Fluid administration significantly improved MAP and reduced heart rate, with a corresponding decline in IVC distensibility among responders. Given its practicality, safety, and diagnostic accuracy, ultrasonographic assessment of the IVC should be incorporated as part of the hemodynamic evaluation algorithm in the ICU, guiding goal-directed fluid therapy and minimizing the risks of fluid overload.

LIMITATIONS

This study was limited by its relatively small sample size and single-center design, which may restrict the generalizability of findings. Variations in ventilatory parameters, intra-abdominal pressures, and operator dependence of ultrasonographic measurements may also influence results. Future multicentric studies with larger populations are needed to establish standardized cut-off values and to assess diIVC performance across different clinical scenarios, including spontaneous breathing and varying modes of ventilation.

CONCLUSION

The present study reinforces that the IVC distensibility index is a valuable, non-invasive predictor of fluid responsiveness in mechanically ventilated critically ill patients. A diIVC cut-off value greater than 18% demonstrated good diagnostic performance in identifying responders. Fluid administration significantly improved MAP and reduced heart rate, with a corresponding decline in IVC distensibility among responders. Given its practicality, safety, and diagnostic accuracy, ultrasonographic assessment of the IVC should be incorporated as part of the hemodynamic evaluation algorithm in the ICU, guiding goal-directed fluid therapy and minimizing risks of fluid overload.

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