



Diagnostic Accuracy of Inferior Vena Cava Collapsibility Index to assess Hypovolemia in Critically ill Patients as compared to Central venous Pressure

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Abstract

Hypovolemia related hemodynamic instability and its complications are common in critically ill patients. The traditional method of volume status estimation is central venous pressure (CVP), which is being replaced by inferior vena cava collapsibility index (IVC-CI) as an easy, inexpensive and non-invasive alternative. The present study is intended to assess the diagnostic accuracy of IVC-CI in determining hypovolemic status in critically ill patients, as compared to CVP. A prospective, diagnostic accuracy assessment study was conducted in 106 critically ill patients and CVP measurements were done from a central venous catheter. Bedside sonography was done to measure the anteroposterior diameter of inferior vena cava (IVCD) at end-inspiration and end-expiration. The formula $[(\text{maximum IVCD} - \text{minimum IVCD}) / \text{maximum IVCD}] \times 100$ was used to calculate IVC-CI. Statistical software SPSS 24.0 was used for analysis and determination of the validity of the test. Of the 106 patients studied, 72 had spontaneous breathing. 46.2% patients had a low CVP value of $< 8 \text{ cm H}_2\text{O}$. The values of inspiratory and expiratory IVC diameters, and IVC-CI were found to be statistically significant in both the spontaneous and the mechanically ventilated groups. In the spontaneous group, an IVC-CI $> 34.8\%$ (sensitivity 76.5%, specificity 100%, positive predictive value 100%, negative predictive value 82.6% and accuracy 88.9%) and in mechanically ventilated patients, IVC-CI $> 52.1\%$ (sensitivity 93.3%, specificity 100%, positive predictive value 100%, negative predictive value 95% and an accuracy 97.1%) were obtained as cut-offs. IVC-CI is well validated in determining hypovolemia in critically ill patients.

Keywords: central venous pressure; inferior vena cava collapsibility index; hypovolemia; spontaneously breathing and mechanically ventilated patients.

Introduction

The assessment of intravascular volume status in critically ill patients is a challenging

task. Fluid management contributes to systemic perfusion and also influences the risk of organ failure and mortality according to a study

by Boyd et al.⁽¹⁾ Intensivists often adopt a fluid management strategy by using invasive hemodynamic monitoring as an adjunct to physical examination and laboratory evaluation of patients. CVP is extensively used for this purpose. In a large-scale survey conducted by McIntyre et al.⁽²⁾, it was found that CVP is used in 90% cases to monitor fluid resuscitation in septic shock patients. High CVP is considered an indicator of volume overload states while low CVP is associated with volume depleted conditions. CVP is an approximation of the right atrial pressure which is a major determinant of right ventricular filling or preload. But numerous complications are associated with central venous catheter insertion including pneumothorax, subcutaneous hematoma, the risk of arterial puncture, hemothorax, catheter malposition, catheter-related infections and asystolic cardiac arrest as reported in many old studies.^(3,4) This has led to extensive research aimed at the development of non-invasive adjuncts to estimate the intravascular volume status. Among the dynamic variables, the most important ones are stroke volume variation, pulse pressure variation, changes in aortic flow velocity, and the diameter of IVC or SVC due to variations in intrathoracic pressure produced by spontaneous respiration or positive pressure ventilation. These are predominantly based on the variations in transpulmonary pressure with respiration which cause variation in cardiac output, as suggested by Bennet et al.⁽⁵⁾ Multiple studies have validated the use of bedside ultrasound to measure IVC parameters to assess volume status.^(6,7,8,9) Sobczyk et al.⁽¹⁰⁾ studied coronary artery bypass graft patients in their immediate post operative period and found that cyclic changes in intra-thoracic pressure result in the collapse of approximately 50% of the IVC diameter. In acute heart failure patients, IVC collapsibility has been found to be useful as an alternative to CVP, to monitor their response to therapy and assist in ongoing resuscitation.^(11,12) Majority of previous studies done in spontaneously breathing patients have found that

there was no significant relation of vena cava diameters to weight, height or body surface area of the patient. The objective of our study is to determine the diagnostic accuracy of ultrasound-guided IVC-CI to detect hypovolemia in critically ill patients, in comparison with CVP values. Our secondary objectives are to assess if IVC-CI is valid in mechanically ventilated patients as well, and to determine the cut-off values of IVC-CI corresponding to low CVP values indicative of hypovolemia.

Patients and Methods

A prospective, diagnostic accuracy assessment study was conducted in the Critical Care Unit of a tertiary care setting from February 2017 to January 2019. 106 patients in the unit, above the age of 18 years and with a functioning central venous catheter insitu, were enrolled in the study by consecutive sampling. Patients in whom supine position was contraindicated or not tolerated, were excluded from the study. Informed written consent was taken from the patients and their relatives and institutional Ethics Committee approval was obtained.

The demographic and basic clinical data of the patients including age, sex, primary illness, ventilatory mode if mechanically ventilated and amount of PEEP administered were recorded in the structured proforma. The IVC assessment by ultrasound and CVP recording were done simultaneously by two different persons. All ultrasonographic measurements were done with the patients in supine position, using the same portable machine (Mindray model Z6, Mindray, NJ, USA) by the same trained faculty member. The curvilinear array probe in the low frequency range of 2-5 MHz (ultrasonic transducer model 3C5P, Mindray, NJ, USA) was used. B mode of ultrasound was initially used for identification of IVC and measurements were done after switching over to M mode. The IVC diameters were measured at a sub-xiphoid location, in the longitudinal axis 1 cm past the IVC-hepatic vein junction where the anterior and posterior walls of

IVC were easily visualized and lie parallel to each other. The antero-posterior diameter of the inferior vena cava were measured duplicately using images frozen according to operator judgement, at the end of inspiration [IVCD(i)] and end of expiration [IVCD(e)]. Measurements in non-intubated patients were obtained during their normal spontaneous inspiration and expiration while trying to avoid valsalva maneuvers. Ventilated patients were evaluated during normal ventilator cycling. In the spontaneously breathing patients, IVCD(i) was the minimum IVC diameter and IVCD(e), the maximum IVC diameter due to negative intrathoracic pressure and IVC collapse. This was vice versa during positive pressure ventilation. In all the subjects, the IVC-CI was calculated using the following equation:

$$\text{IVC-CI} = \frac{(\text{maximum IVCD} - \text{minimum IVCD})}{\text{maximum IVCD}} \times 100.$$

CVP values were recorded in the supine position simultaneously with IVC evaluation. This was done by the researcher herself using a pressure transducer attached to the central venous catheter and connected to the monitor. The transducer was zeroed at the level of heart and the same fluid-filled (saline solution) system was used for all patients. The person who performed the ultrasound study and the one who recorded CVP values, were blinded to the data obtained by each other. Fluid input during the study period was determined based on clinical criteria like blood pressure, heart rate and patient observation, by the ICU in-charge who was also blinded to the study. CVP

value $< 8 \text{ cm H}_2\text{O}$ was considered hypovolemic for our study. This CVP cut-off was set based on a study by Thanakitcharu et al.⁽¹¹⁾ which supported the correlation between CVP and IVC-CI. Similar CVP value cut-off for hypovolemia is used in our institution for patient management.

Data was entered into Microsoft excel sheet and analysed using SPSS software (version 24.0). Continuous variables were expressed as mean values with standard deviation. Data for spontaneously breathing and mechanically

ventilated patients were compared using unpaired t-test. ROC curve was generated to find out the optimal cut off values of IVC-CI for estimating low CVP value, defined as $< 8 \text{ cmH}_2\text{O}$. The AUC, accuracy, sensitivity, specificity, positive and negative predictive values were determined. A paired sampled t-test was used to compute the p-values and $p \leq 0.05$ was considered statistically significant.

Results

Among the study subjects, 72 had spontaneous respiration while 34 were on mechanical ventilation. Of the total 106 patients, 54(50.9%) belonged to the older age group of 51-70 years. The mean age of the patients in the spontaneous group was 47.5 ± 12.9 years and in the mechanically ventilated group was 49.7 ± 12.6 years. The study population included 57(53.8%) males and 49(46.2%) females. The spontaneous group had 42(58.3%) males and 30(41.7%) females while the mechanically ventilated group had 15(44.1%) males and 19(55.9%) females.

CVP values were low ($< 8 \text{ cm H}_2\text{O}$) in 49(46.2%) subjects of which 34(47.2%) were in the spontaneous breathing group and 15(44.1%) were mechanically ventilated. The mean CVP was $8.43 \pm 2.07 \text{ cm H}_2\text{O}$ in the spontaneous group and $8.44 \pm 2.22 \text{ cm H}_2\text{O}$ in the ventilated category. The mean value of the inspiratory IVC diameter was $1.24 \pm 0.24 \text{ cm}$ in the spontaneous group and $1.83 \pm 0.13 \text{ cm}$ in the other group. The mean value of the expiratory IVC diameter was $1.85 \pm 0.11 \text{ cm}$ in the spontaneous group and $1.29 \pm 0.24 \text{ cm}$ in the mechanical ventilation group.

Regarding the IVC-CI values, the mean was 33.47 ± 9.36 in the spontaneous group and 45.52 ± 17.02 in the ventilated group. Figure 1 illustrates the box plot representation of IVC-CI of the two groups.

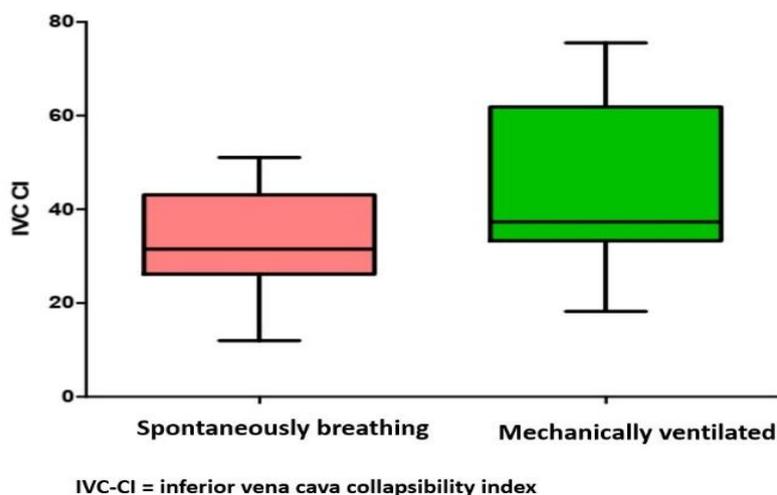


Figure 1: Box plot representation of IVC-CI of spontaneously breathing and mechanically ventilated patients

The demographics are shown in Table 1.

Table 1: Demography of the Study Population

Characteristics	Spontaneously breathing	Mechanically Ventilated
Age (Mean ± sd)	47.5 ± 12.9 years	49.7 ± 12.6 years
Male patients, n(%)	42 (58.3%)	15 (44.1%)
CVP (Mean ± sd)	8.43 ± 2.07 cm H ₂ O	8.44 ± 2.22 cm H ₂ O
Hypovolemic group, n(%)	34 (47.2%)	15 (44.1%)
IVCD(i) (Mean ± sd)	1.24 ± 0.24 cm	1.83 ± 0.13 cm
IVCD(e) (Mean ± sd)	1.85 ± 0.11 cm	1.29 ± 0.24 cm
IVC-CI (Mean ± sd)	33.47 ± 9.36	45.52 ± 17.02

CVP = central venous pressure, IVCD(i) = inferior vena cava diameter at end inspiration, IVCD(e) = inferior vena cava diameter at end expiration, IVC-CI = inferior vena cava collapsibility index

Among the 34 mechanically ventilated patients, 17(50%) were with positive end-expiratory pressure (PEEP) of 5 cm H₂O and the other half without PEEP.

When CVP was correlated with IVC-CI, 26(76.5%) spontaneously breathing patients and

14(93.3%) mechanically ventilated patients with low CVP (8 cm H₂O) had IVC-CI >40. For the spontaneous breathing group, ROC curve as in Figure 2 was plotted.

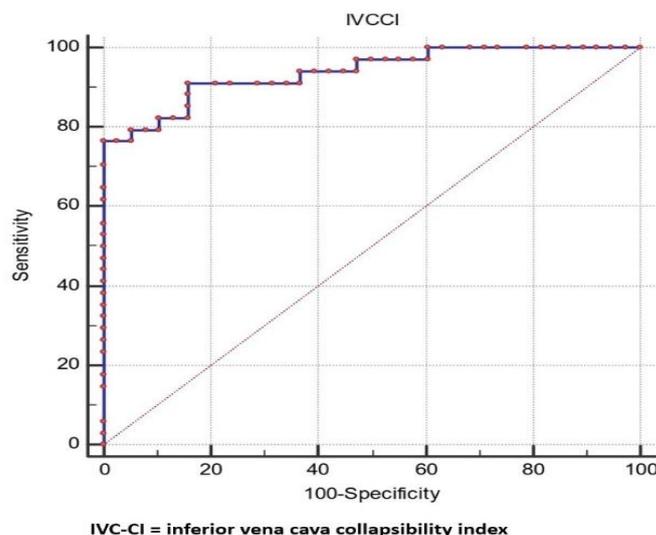


Figure 2: ROC curve showing IVC-CI cut-offs for detection of hypovolemia in spontaneously breathing population

The data used for ROC curve and the optimal IVC-CI criterion obtained are shown in Table 2.

Table 2: Data for Roc Curve and Optimal IVC-CI Criterion in Spontaneously Breathing Patients

Variable	IVC-CI* in spontaneously breathing	IVC-CI* in mechanically ventilated
Classification variable	CVP	CVP
Sample size	72	34
Positive group (CVP**<8 cm H ₂ O)	34	15
Negative group (CVP**>8 cm H ₂ O)	38	19
Area under the ROC curve***	0.939	0.968
Standard error	0.0274	0.0325
95% Confidence interval	0.856-0.982	0.843-0.999
Significance level p (area=0.5)	<0.0001	<0.0001
Optimal criterion	>34.8	>52.1
Sensitivity	76.5%	93.33%
Specificity	100%	100%
Positive predictive value	100%	100%
Negative predictive value	82.6%	95%
Accuracy	88.9%	97.1%

* IVC-CI = Inferior vena cava Collapsibility Index, ** CVP = Central Venous Pressure, *** ROC = Receiver Operating Characteristics

The area under the ROC curve was 93.9% and IVC-CI > 34.8% showed sensitivity 76.5%, specificity 100%, positive predictive value 100%, negative predictive value 82.6% and accuracy 88.9% as represented in Table 2.

In the mechanically ventilated category, ROC curve was plotted as in Figure 3.

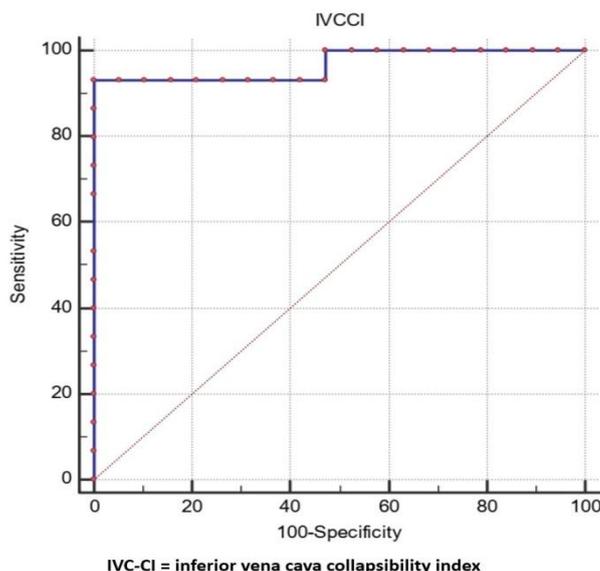


Figure 3: ROC curve showing IVC-CI cut-offs for detection of hypovolemia in mechanically ventilated population

Table 2 illustrates the data used for ROC curve as well as the optimal criterion obtained. Area under the ROC curve was 96.8% and IVC-CI > 52.1% was the optimal criterion as represented in Table 2. It had sensitivity 93.3%, specificity 100%, positive predictive value 100%, negative predictive value 95% and an accuracy 97.1%.

Discussion

In the diagnostic test evaluation of 106 ICU patients, 72 were spontaneously breathing while 34 were mechanically ventilated with a PEEP of 5 cm H₂O in 50%. A study by Citilcioglu et al.⁽¹³⁾ demonstrated similar PEEP values in mechanically ventilated patients. Majority of

patients belonged to the older age group of 51-70 years in both the spontaneous and mechanically ventilated categories. Males were more in the total study population and the spontaneous group and is representative of the larger proportion of male patients admitted in the CCU at any point of time. This may be due to multiple factors like higher incidence of road traffic accidents, substance abuse and multiple comorbidities which necessitate intensive care management among males more than females.

The mean CVP value obtained in both the spontaneous and mechanically ventilated group was around 8 cm H₂O. Similar findings were obtained by Taniguchi et al.⁽¹⁴⁾ in their study regarding impact of body size on IVC parameters to estimate right atrial pressure. All patients who were found to have low CVP values were promptly managed without delay. The IVC-CI was analysed by grouping into four - <20, 20-30, 30.1-40 and > 40%. In our study, the majority of patients had an IVC-CI above 40 and most of them had low CVP. ROC curves were drawn separately for the spontaneous and the mechanically ventilated groups to determine the cut-off values of IVC-CI for patients with low CVP. IVC-CI > 34.8 and >52.1 were obtained in the spontaneous and mechanically ventilated groups respectively with good sensitivity, specificity, accuracy, positive and negative predictive values. Previous studies to estimate right atrial pressures using IVC parameters have come out with similar results.^(14,15,16)

The limitations of our study include requirement of higher PEEP in severe acute respiratory distress syndrome (ARDS) patients to maintain oxygenation. We have used all or none rule with a PEEP of 0 or 5 in ventilated patients, but if the PEEP values were to increase, increasing intrathoracic pressure would have resulted in decrease in IVC compliance and lead to false negative results, as suggested in a study by Charron et al.⁽¹⁷⁾ The validity of IVC-CI estimation is also debatable in ventilated patients having respiratory efforts, either in assisted or

spontaneous mode. Via et al. did a study in 2016 concluding that IVC ultrasound may fail to predict fluid responsiveness in such patients.⁽¹⁸⁾

Conclusion

Inferior vena cava collapsibility is well validated in determining hypovolemia in critically ill patients. It has got a good sensitivity, specificity and positive predictive value in both the spontaneously breathing and mechanically ventilated groups. Moreover, inspiratory and expiratory inferior vena cava diameters were also significant in determining intravascular volume status. Thus, the use of inferior venacava parameters by bedside ultrasonography is an invaluable tool in the management of critically ill patients, and can replace the conventional invasive methods.

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