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Assessment of Intravascular Volume Status by Measuring Ultrasound Guided Inferior Vena Caval Collapsibility Index in Critically ill Patients

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Abstract **Original Research Article**

Background: Accurate assessment of intravascular volume status is one of the most challenging and important tasks in the care of critically ill patients. There are some invasive and non-invasive parameters for volume status assessment. Central venous pressure (CVP) is an invasive measure for intravascular volume status assessment and has been associated with many complications. The IVC-CI can provide a useful guide for noninvasive intravascular volume status assessment of critically-ill patients. ***Methodology:*** This Cross-sectional study was carried out in the ICU, BSMMU after permission from the Institutional Review Board of BSMMU. A total 120 critically-ill patients on positive pressure ventilation in the intensive care unit was assessed for eligibility. All ultrasonographic examinations were performed in the adequately sedated mechanically ventilated patients in supine position by investigator using a portable ultrasound device sonoscape S2. Sonographic evaluation of IVC-CI was performed via an initial B-mode. The maximum and minimum IVC diameter was measured without regard to phase of the respiratory cycle. The CVP was also measured in the supine position immediately after the IVC evaluation. It was used as the reference parameter for stratifying each patient's intravascular volume status. IVC-CI measurements was grouped by range (<0.20, 0.20 to 0.50, and >0.50) and analyzed for presence of substantial differences in CVP between the three IVC-CI groupings. IVC-CI was correlated with CVP value. Sensitivity and specificity of IVC-CI were also calculated. ***Results:*** A total of 48/110 (40%) females and 72/120 (60%) males were included in the study with a mean age of 53.3 ± 13.1 years. The mean central venous pressure maintained was 12.53±3.26 mmHg in group III, 7.05±1.43 mmHg in group I and 2.69±1.06 mmHg in group II with the inferior vena cava collapsibility index (IVC-CI) was 0.59±0.05 in group I, 0.34±0.09 in group II and 0.21±0.11 in group III. The difference was statistically significant ($p<0.05$) among three groups. There was a statistically significant relation among the mean CVP pressure, the IVC collapsibility index, the mean maximum and minimum IVC between groups as determined by one-way analysis of variance (ANOVA) ($p < 0.005$). There was a strong negative correlation between CVP and IVC collapsibility index, which was statistically significant ($r = -0.659$, $n = 120$, $p = 0.0001$). ***Conclusion:*** In the present study, it can be concluded that the IVC-CI is a better alternative tool of CVP monitoring to determine intravascular volume status assessment in critically ill patients.

Keywords: Ultrasound, intravascular, respiratory, sonograpghic.

INTRODUCTION

Accurate assessment of intravascular volume status is one of the most challenging and important tasks in the care of critically ill patients. Hemodynamic evaluation of the critically-ill patient continues to pretend a significant challenge, with lack of a reliable and reproducible "gold standard" for intravascular volume assessment [1]. Currently there are a variety of methods available for assessing a patient's intravascular volume status. Clinical assessment of volume status using physical examination parameters (e,g. pulse, blood pressure, capillary refill, JVP, urine output, mucous membrane, temperature, dyspnea etc) are inaccurate [2]. No single clinical parameter is useful in identifying a low circulating blood volume [3].

There are some invasive and non-invasive parameters for volume status assessment. A European survey of anesthesiologists reported that more than 90% used CVP to guide fluid management [4]. CVP is a good approximation of right atrial pressure (RAP) which in turn is a major determinant to right ventricular filling. All invasive procedures have its own

complications and the risk of 15% is noted for CV line placement [5]. There are also some disadvantages with central venous line such as prolonged hospitalization, increase in health care cost, reduced quality of life. It is preferred to substitute it by a reliable noninvasive method [6]. So a noninvasive modality would be desirable for diagnostic and therapeutic management of critically ill patient [7]. Studies suggest that bedside ultrasonography of the vena cava may have utility in assessing intravascular volume status.

Ultrasound is a tool that potentially could provide a rapid, repeatable and non-invasive means of gauging preload and the need for fluid resuscitation. Because ultrasound machines are relatively light and portable, and many clinicians are trained in their use (e.g., emergency physicians, anesthesiologists, intensivists, and surgeons), the ability to non-invasively measure CVP could extend patient monitoring capabilities to a variety of settings where direct measurements of the CVP are unavailable or impractical. Determination of inferior vena caval collapsibility index (IVC-CI) has been found to correlate with intravascular volume status [8].

The IVC can be assessed with static measures (diameter) or with dynamic measures (respirophasic variation). In a spontaneously breathing patient, negative intrathoracic pressure generated during inspiration draws blood from the IVC into the right atrium, resulting in varying degrees of IVC collapse. Cyclic changes in intra-thoracic pressure may result in collapse of the IVC diameter of approximately 50% [9]. Therefore, IVC diameter measurements could also be assisted in ongoing resuscitation by providing a means to measure CVP non-invasively.

Measurements of IVC collapse are commonly reported as the "collapsibility index," which is calculated as (maximum IVC diameter on expiration - minimum IVC diameter on inspiration/maximum IVC diameter on expiration) in spontaneously breathing patients. In mechanically ventilated patient, positive pressure ventilation reverse the normal inspiratory and expiratory pressure gradients between the thoracic and abdominal cavity. As a result, IVC diameter increases during inspiration. Studies of IVC respirophasic variation in mechanically ventilated patients are typically performed with fixed tidal volume in adequately sedated patients with controlled ventilation. In mechanically ventilated patients, the "collapsibility index" is calculated as (maximum IVC diameter on inspiration-minimum IVC diameter on expiration/(maximum IVC diameter on inspiration). The term "caval index"(CI) has been used to refer to respirophasic changes in IVC diameter irrespective of whether the patient is spontaneously breathing or receiving mechanical ventilation [10].

Previous studies show that there are significant correlation between CVP and IVC-CI but some controversary in mechanically ventilated patient. There is no significant correlation between IVC parameter and CVP under mechanical ventilation in pediatric patient [11]. So additional large-scale clinical trial is required to determine the accuracy of IVC-US measurements in diverse populations [10]. So our goal is to determine the accuracy of IVC-CI in mechanically ventilated patient.

METHODS AND MATERIALS

This Cross sectional study was carried out in the Department of Anaesthesia, Analgesia and Intensive Care Medicine, BSMMU, Dhaka-1000 and patients were recruited from ICU, BSMMU according to inclusions & exclusions criteria after permission from the Institutional Review Board of BSMMU and study period was 24 months.

A total 120 critically-ill patients on positive pressure ventilation in the intensive care unit who had already been placed with a central venous catheter for CVP monitoring, according to their clinical indications, was assessed for eligibility and given a data sheet number. All ultrasonographic examinations were performed with the patients in supine position by investigator using a portable ultrasound device Sonoscape S2. Before the IVC diameter evaluation, investigator was not informed of the hemodynamic and CVP data. Subcostal or subxiphoid windows was used based on available views, patient habitus, presence of external barriers (eg, drains, surgical dressings), and preference of sonologist. Sonograpghic evaluation of IVC-CI was performed via an initial B-mode. After localizing the IVC, the dynamic diameter change was recorded over time using the M-mode in order to identify and measure the maximum and minimum venous dimensions over the respiratory cycle. Studies of IVC respirophasic variation in mechanically ventilated patients were performed with particular tidal volume in adequately sedated patients. Patients were evaluated during normal ventilatory cycling. The CVP was also measured in the supine position immediately after the IVC evaluation. CVP was measured using an indwelling central venous catheter (CVC) and a transducer. It was used as the reference parameter for stratifying each patient's intravascular volume status. The CVC was attached to intravenous fluid within a pressure bag. Measurements were taken with the patient in a semi-recumbent position. The position was remaining the same for each measurement taken to ensure an accurate comparable result. CVP trace was observed on the monitor. The normal range of CVP measurement is 5-10 mm of Hg and this was used for determining the euvolemic status (group II), CVP less than 5 mm of Hg was determined as hypovolemic (group I) and CVP more than 10 mm of Hg was determined as hypervolemic status (group III). IVC-CI measurements was grouped by range IVC-CI <0.20 (group III), IVC-CI 0.20 to 0.50 (group II), and IVC-CI

> 0.50 (group I) . Then IVC-CI was analyzed for presence of substantial differences in between the three CVP groups. IVC-CI was correlated with CVP value. Among the three groups, with respect to their intravascular volume status, the systolic and diastolic blood pressure, mean blood pressure, the pulse pressure was also analyzed. Sensitivity and specificity of IVC-CI was also calculated.

STATISTICAL ANALYSIS

Sample size estimation based on correlation analysis was used for determining the sample size in the present study, and the correlation as reported by Stawicki et al., was used as a reference value. The statistical analysis was carried out using the Statistical Package for Social Sciences version 23.0 for Windows (SPSS Inc., Chicago, Illinois, USA). Qualitative variables were expressed as frequencies, percentages. Quantitative variables were expressed as mean±standard deviation. Chi square test was done for qualitative variables among hypovolemic, euvolemic and hypervolemic group. ANOVA was utilized for comparison among the 3 groups of patients with different intravascular volume status. Pearson's correlation coefficient was done between CVP and IVC-CI. A "p" value <0.05 was considered as significant.

RESULTS AND OBSERVATIONS

This Cross-sectional study was conducted among study population at Department of Anaesthesia, Analgesia and Intensive Care Medicine, BSMMU. This study was done to assess intravascular volume status by measuring ultrasound guided inferior vena caval collapsibility index (IVC-CI) in critically ill patients.

The studied groups became statistically not significant for age in years (p=690). Sex difference was analyzed by chi-square test and the studied groups were matched for sex (p=0.831). It was observed that major disease of ICU patients had sepsis which was 34(28.3%), post operative 24(20.0%), RTA with head injury 20(16.7%) and Acute respiratory distress syndrome (ARDS) 12(10.0%). Highest extrinsic PEEP was 3 mm Hg and lowest was 1 mm Hg. The mean PEEP was found 2.31±0.821 in group I, 2.19±0.81 group II and 1.89±0.88 group III. This ranged was within physiological limit.

Systolic BP was higher in group III 126.7±15.2 mmHg, 118.7+21.0 mmHg in group I and 114.0±14.4 mmHg in group II. Diastolic BP was higher in group III 84.1±8.7 mmHg, 82.6±9.5 mmHg in group II and 79.9±14.6 mmHg in group I. Mean BP was higher in group III 88.5±11.6 mmHg, 86.0±10.89 mmHg in group II and 82.6±12.2 mmHg in group I. Pulse pressure higher in group III 40.3±16.1 mmHg, 37.9±8.5 mmHg in group II and 34.5±10.8 mmHg in group I. The difference was statistically not significant (p>0.05) among three groups. The mean heart rate was 85.3±15.9 per minute in group III, 83.1±17.2 per minute in group I and 78.5±12.1 per minute in group II.

Table-1: Distribution of the studied patients according to Clinical parameters (n=120)

Parameters	Group I (n=58)		Group II (n=43)		Group III (n=19)		P value
	Mean	±SD	Mean	±SD	Mean	±SD	
Systolic BP (mmHg)	118.7+21.0		114.0±14.4		126.7±15.2		0.061^{ns}
Range (min-max)	70-140		88-170		100-150		
Diastolic BP (mmHg)	79.9±14.6		82.6±9.5		84.1±8.7		0.361^{ns}
Range (min-max)	45-100		55-110		70-100		
Mean BP (mmHg)	82.6±12.2		86.0±10.89		88.5±11.6		0.134^{ns}
Range (min-max)	57-113		67-130		83-123		
Pulse (beat per minute)	83.1±17.2		78.5±12.1		85.3±15.9		0.197^{ns}
Range (min-max)	56-130		57-110		66-120		
Pulse pressure (mm Hg)	34.5±10.8		37.9±8.5		40.3±16.1		0.120^{ns}
Range (min-max)	12-50		18-60		15-80		

s= significant
ns= not significant, P value reached from ANOVA test

The mean central venous pressure maintained was 12.53±3.26 mmHg in group III, 7.05±1.43 mmHg in group I and 2.69±1.06 mmHg in group II. P value was 0.001 that was statistically significant. P value reached from ANOVA test

The inferior vena caval (IVC) mean maximum diameter was 1.40±0.19 cm in group III, 1.20±0.26 cm in group II and 1.18±0.13 cm in group I. The difference was statistically significant (p<0.05) among three groups. P value reached from ANOVA test. The mean inferior vena cava (IVC) minimum diameter was 1.40±0.19 cm in group III, 1.20±0.26 cm in group II and 1.18±0.13 cm in group I. The difference was statistically significant (p<0.05) among three groups P value reached from ANOVA test. The inferior venal caval collapsibility index (IVC-CI) was 0.59±0.05 in group I, 0.34±0.09 in group II and 0.21±0.11 in group

III. The difference was statistically significant ($p<0.05$) among three groups.

Correlation was done between CVP and IVC-CI by Pearson's correlation coefficient. There was a significant negative correlation (r=-0.659; p=0.001) between CVP and IVC-CI.

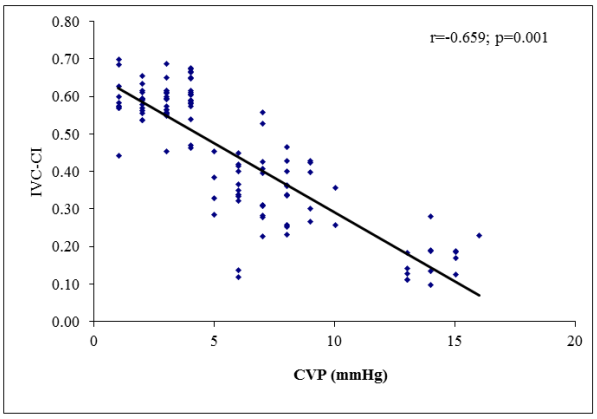

Fig-1: Scatter diagram shows significant negative correlation (r=-0.659; p=0.001) between CVP and IVC-CI

In current IVC-CI, it was observed that, true positive 65 cases, false positive 12 cases, false negative 6 cases and true negative 37 cases are identified.

Table-2: Sensitivity, specificity, accuracy, positive and negative predictive values of IVC-CI and CVP

Validity test	IVC-CI (%)
Sensitivity	91.55
Specificity	75.51
Accuracy	85.00
Positive predictive value	84.42
Negative predictive value	86.05

The validity test of IVC-CI has sensitivity 91.55%, specificity 75.51%, accuracy 85.00% and positive predictive values 84.42% and negative predictive value 86.05%

DISCUSSION

Accurate assessment of a patient's volume status is a critical task in the care of critically ill patients. CVP monitoring is a useful tool for guiding fluid management and monitoring but it requires placement of a central venous catheter, which is an invasive procedure and is associated with complications. IVC-CI is a non-invasive parameter quickly performed at the bedside, cheap, easy to find and with little to no risk to the patient.

In this present study, it was observed that higher numbers of elderly patients were admitted in our ICU. Mean age was more than 52 years among three groups. Ilyas et al., showed the mean age was 50.4±19.3 years in their study patients [12]. With increasing of age, functional reserves often decrease and comorbidities increase. Older patients are more prone to die and also prone to be referred to ICU at a large number from other wards. All these factors may contribute to admit more elderly patients in ICU. Central venous pressure (CVP) monitoring is usually performed in ICU patients for volume depleted states and volume overload states. CVP value was used as reference for grouping and correlation was done between CVP and IVC-CI. The mean central venous pressure maintained was 12.53±3.26 mmHg in group III, 7.05±1.43 mmHg in group II and 2.69±1.06 mmHg in group I. Thanakitcharu et al., study showed the mean CVP was 5.32±1.49 cm of H2O in Hypovolemia, 10.67±1.29 cm of H2O in Euvolemia and 16.89±2.99 cm of H2O in Hypervolemia [13]. These differences may be due to volume depletion, different unit of CVP and exclusion of spontaneously breathing patients in our study.

The maximum, minimum and mean inferior vena caval (IVC) diameter were highest in group III and lowest in group I. The difference was statistically significant ($p<0.05$) among three groups. These indicate that grouping was also justified by IVC values. Ilyas et al., also obtained in their study that there was a statistically significant differences among three groups [12].

The inferior venal caval collapsibility index (IVC-CI) is ranged from 0 to 1. If IVC-CI is 0, that indicates maximum volume overload and if it is 1, then maximum volume depletion will be observed. The IVC-CI was 0.59±0.05 in group I, 0.34±0.09 in group II and 0.21±0.11 in group III and was significantly higher ($p<0.05$) in group I followed by group II and group III. The differences were statistically significant ($p<0.05$) among three groups that indicates grouping was also justified by IVC-CI values. Similar findings also observed by Thanakitcharu et al., [13].

IVC-CI utilizes the interplay between the compliance of the IVC and cyclical changes in intra-thoracic pressure during the respiratory cycle. In this study, strong negative correlation(r=-0.659; p=0.001) was seen between CVP and IVC-CI. The IVC is a highly collapsible major vein. The diameter of IVC is altered by respiration, blood volume, and right heart function. So, it reflects volume status and acts as a reservoir. In mechanically ventilated hypovolemic patients, IVC diameter collapses more during expiration; as a result IVC-CI values are highest in the patients with lowest CVP group. The opposite result was seen in hypervolemic group. Similarly, Ilyas et al., showed there was a strong negative correlation between CVP and IVC collapsibility index (%), which was statistically significant ($r = -0.827$, $p<0.05$) [12]. They included both spontaneously and mechanically ventilated patients. So r value of our study may vary for this reason. In another study Thanakitcharu et al.,

obtained that the highest significant correlation was found between the CVP and IVC-CI ($r = -0.612$, $p < 0.001$) [13]. Similar observations regarding the correlation between CVP and IVC-CI were also observed by Yang [14], Lyon & Verma [9] and Stawicki et al., [15], Brennen et al., [16] documented that the combination of both collapsibility indices (CI) and IVC diameter measurements may assist in improved ultrasonographic evaluations of the IVC with clinically important categories of right atrial pressure.

In current IVC-CI, it was observed that, true positive 65 cases, false positive 12 cases, false negative 6 cases and true negative 37 cases are identified. The validity test of IVC-CI had sensitivity 91.55%, specificity 75.51%, accuracy 85.00% and positive predictive values 84.42% and negative predictive value 86.05%. Inta-abdominal pressure may influence IVC-CI. In our study, only risk factor of intra-abdominal hypertension was excluded. No measurement technique of intra-abdominal pressure was used. It may be a cause of low specificity of IVC-CI in our study. Barbier et al., demonstrated that using a threshold CI of 18%, mechanically ventilated septic responders and nonresponders could be discriminated with 90% sensitivity and specificity [17]. Feissel et al., reported a threshold CI of 12% could discriminate mechanically ventilated septic responders and nonresponders with positive and negative predictive values of 93% and 92%, respectively [18]. In another study Feissel et al., found IVC-CI had positive predictive value of 93.0% and a negative predictive value of 92.0%. In their study, sensitivity and specificity of IVC-CI was observed for fluid responsiveness [18]. So these variations may occur.

CONCLUSION

The assessment of intravascular volume status remains one of the most challenging diagnostic problems in critically ill patient. IVC-CI is a sensitive and specific diagnostic modality for noninvasive intravascular volume status assessment in critically ill patients. Although Sample size was small of the present study. Therefore, in future further study may be under taken with large sample size. In the present study, it can be concluded that the IVC-CI is a better alternative tool of CVP monitoring to determine intravascular volume status assessment in critically ill patients.

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