Original Research Article

USG guided determination of inferior vena cava diameter and collapsibility index for non-invasive evaluation of intravascular volume status as an alternative to invasive CVP measurement

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Abstract

Background: Fluid management in crucial for critically ill patients and Intravascular volume status is an essential parameter for diagnosis and management of such patients. CVP has been used traditionally for intravascular volume status assessment but being expensive, invasive, expertise requiring and time consuming, it is not that suitable. So this study aims to determine whether IVCD and IVCCI can be used as non-invasive alternative to CVP. **Methods:** A prospective, cross sectional study conducted in the ICU and OTs over a period of one year, 60 patients with an indication of central venous catheterisation were enrolled. USG guided central line secured in right IJV and transduced. At single point of time CVP value noted by OTA and USG guided IVC diameter measured during both end inspiration and end expiration by resident. IVCCI calculated for each patient. The data was then analysed statistically using SPSS for windows. **Results:** A highly significant positive correlation was found between IVCD at end expiration and CVP(r=0.550, p=0.000) as well as between IVCD at end inspiration and CVP(r=0.585, p=0.000). Whereas a negative correlation found between IVCCI and CVP but was not statistically significant(r=0.235, p=0.071). **Conclusion:** IVCD both end expiratory and end inspiratory measured by bedside USG can be used for determination of intravascular volume status.

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INTRODUCTION

In case of critically ill patients, regardless of the cause of patient's status, the intravascular (I/V) volume, is clearly of prime importance. The early detection of I/V volume status and a subsequent rapid initiation of effective treatment increases the survival rates of these patients.[1,2] It is important to give adequate amount of fluid to patient as, too little fluid may result in tissue hypoperfusion and worsen organ dysfunction; however, over-prescription of fluid also appears to impede oxygen delivery and compromise patient outcome.[3] Invasive hemodynamic monitoring of central venous pressure (CVP) has been considered to be the standard criteria when assessing intravascular volume. However, obtaining central venous pressure (CVP) measurements require an invasive procedure and has practical limitations for its routine use in patients with coagulopathy or bleeding disorders usually seen in critically ill and in paediatric patients.[4] Central venous catheterisation is associated with over 15% complication rate.[4] These can be mechanical complications like arterial puncture and cannulation, hematoma, hemothorax, surrounding nerve injuries, pneumothorax, embolisation of broken catheter or guide wire, air embolism, arrhythmias, lymphatic system injury,

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infectious complications like sepsis, endocarditis and thrombotic complications like venous thrombosis, pulmonary embolism etc.[4] Most of these complications can be minimised but not abolished by ultrasound (USG) guided central venous pressure (CVP) access. Thus this study aims to introduce USG guided assessment of IVC diameters and collapsibility index for non invasive evaluation of intravascular volume status as an alternative to invasive CVP in order to provide bedside clinicians with new option for assessing intravascular volume status.

The inferior vena cava collapsibility index (IVCCI) can be calculated by an equation given below:

$$IVCCI = \frac{e\ IVCD - i\ IVCD}{e\ IVCD} \times 100$$

Where IVCCI = Inferior vena cava collapsibility index
e IVCD = Inferior vena cava diameter at end expiration
i IVCD = Inferior vena cava diameter at end inspiration

In the past, studies have been done on the correlation between CVP and IVC parameters but they are scarce with variable results so it seems hazardeous to manage fluids in a spontaneously breathing patient by using IVC respiratory variations only until further data is established.[5,6]

Keeping in mind, the role of goal directed early fluid management in decreasing the mortality of critically ill patients and limitations of standard method of I/V fluid assessment through CVP monitoring, this study was conceived to clarify the role of non invasive and rapid assessment of I/V volume status using USG guided IVC parameters for early and adequate fluid management.

MATERIAL AND METHODS

The study was conducted in the department of Anaesthesiology, Dr.R.P.G.M.C, Kangra at Tanda, Himachal Pradesh after approval of protocol review committee and institutional ethical committee. OT patients and critically-ill patients, scheduled for surgery with central venous access indication, on spontaneous ventilation with accessible epigastric region for ultrasonography were enrolled for the study. The procedure was explained to the patients and there after written informed consent was taken. Following patients were not included in the study.

- Patient's refusal.
- Patients on ventilatory support.
- Patients having abnormal coagulation profile.
- Patients with right paramedian incision in upper abdomen.

Before commencing the procedure, a case record form was filled for each patient. Patient's demographic data included age, sex, weight, height and BMI. ASA grade, biochemical tests and hemogram of the patient was also recorded.

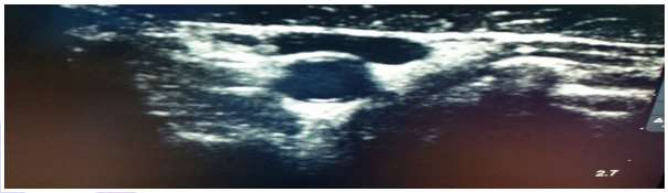

Figure 1: USG image showing confirmation of IJV by compressing the vessels.

Under all aseptic precautions, central venous access achieved in right internal jugular vein under USG guidance with 7-13 hz probe, using saldinger technique and CVP line transduced. CVP value was noted by one person, not involved ina the study. Thus researchers were blinded to the CVP readings during the study. At the same point of time, USG imaging was performed in the longitudinal plane, measured on 2D mode during end inspiration and end expiration of same respiratory cycle after asking the patient to take deep and long breath, hold and then exhale. All diameters were determined using frozen 2D images and measured in centimetres.

Figure 2

Figure 3

Figure 2: Method to hold the probe for longitudinal view of IVC; **Figure 3:** Method of probe placement and USG view obtained.

For bedside ultrasonography we used Sonosite Micromax USG machine to measure the IVC diameters, with low frequency (2-5 MHz) curvilinear probe and xiphoid approach. The measurement was taken approximately 2 mm caudal to the inflow of hepatic veins, where anteroposterior(AP) internal diameter of IVC was measured.

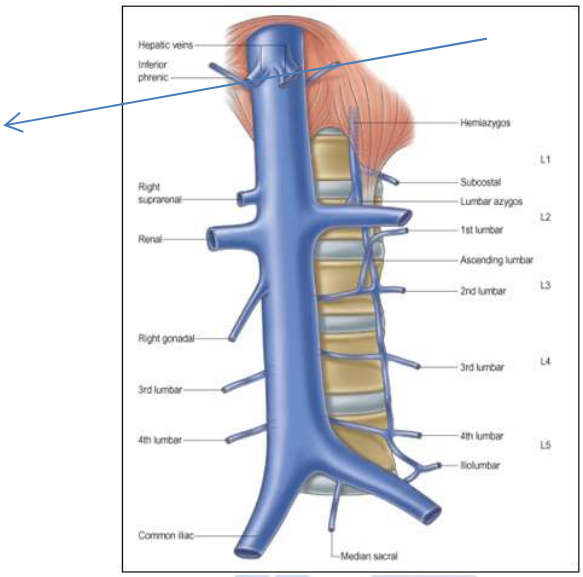

Figure 4: IVC with its tributaries (Source: www.biswaforum.com)

The measurement was taken approximately 2 mm caudal to the inflow of hepatic veins, where anteroposterior(AP) internal diameter of IVC was measured. The AP diameter of IVC, both end-inspiratory (i IVCD) and end-expiratory (e IVCD) diameters at the end of inspiration and end of expiration, was then recorded. The IVC collapsibility index (IVCCI) was calculated by an equation given below and then was compared with the central venous pressure (CVP) value.

$$IVCCI = \frac{e\ IVCD - i\ IVCD}{e\ IVCD} \times 100$$

Where IVCCI = Inferior vena cava collapsibility index
e IVCD = Inferior vena cava diameter at end expiration
i IVCD = Inferior vena cava diameter at end inspiration
The inferior vena cava diameters (IVCD) and corresponding central venous pressure (CVP) were then recorded. The results were plotted in graphical manner and in tabular form.
The IVC diameter during end inspiration and end expiration was measured in cm and the collapsibility index was calculated as percentage. The CVP measurement was recorded as mm of Hg. All the data was collected using standard data collection format MS excel 2010 version and were coded into SPSS software version. The continuous data distribution was tested for mean and median for descriptive data. The correlation data was analysed and regression analysis was done.

OBSERVATIONS AND RESULTS

Table 1: Table depicting mean values of the parameters measured.

Parameters	Mean value
Age	52.12 years
BMI	20.72 $\pm$ 3.87 kg/m^2
eIVCD	1.52 cm $\pm$ 0.47 cm
iIVCD	0.91 $\pm$ 0.40 cm
IVCCI	40.18 $\pm$ 18.40
CVP	8.84 $\pm$ 3.57 mm Hg

Total of 64 cases were recruited during the study period. 4 patients were excluded from study as IVC was not localised on USG in those patients. Out of the 60 cases, 33 were male and 27 were females. Mean age was calculated as 52.12 years with standard deviation of 20.64 years and median age was 55.50 years as depicted in table above.
The mean BMI of the population studied was 20.72 $\pm$ 3.87 kg/m^2 with minimum BMI of 13 kg/ m^2 and maximum BMI of 34.27 kg/m^2.

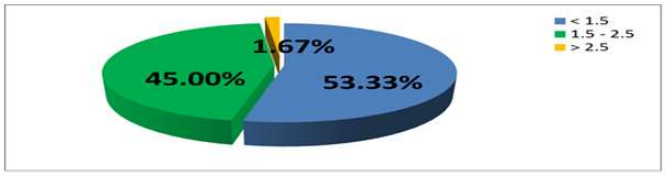

Figure 5: Pie chart depicting Patient distribution on the basis of e IVCD

Mean diameter of inferior vena cava at end expiration was 1.52 cm ± 0.47 cm.
Out of 60 cases enrolled 32 (53.3%) were having IVC diameter of <1.5 cm on end expiration. The end expiration diameter of IVC was between 1.5 to 2.5 cm in 27 patients (45%) and only1 patient (1.7%) was having IVC with end expiratory diameter of >2.5 cm.

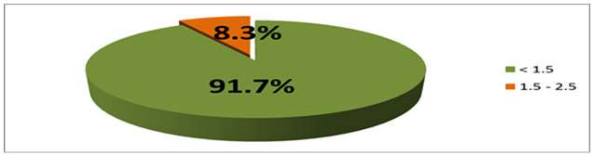

Figure 6: Pie chart depicting Patient distribution on the basis of i IVCD

Mean diameter of inferior vena cava at the end of inspiration was 0.91 ± 0.40 cm
Out of 60 cases enrolled 55 (91.7%) were having IVC diameter of <1.5 cm on end inspiration. The end inspiration diameter of IVC was between 1.5 to 2.5 cm in 5 patients (8.3%).

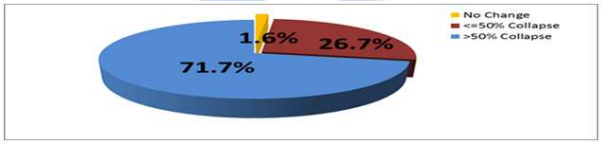

Figure 7: Pie chart depicting Patient distribution on the basis of IVCC

Mean IVCCI of the patients in the study was 40.18 ± 18.40.
Out of 60 cases enrolled 43 (71.7%) were having IVCCI of <50%, 16 (26.7%) were having IVCCI of >50% and only 1 patient (1.6%) was having IVCCI of zero.

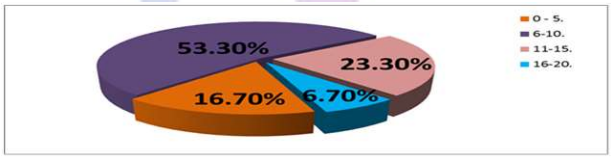

Figure 8: Pie chart depicting Patient distribution on the basis of CVP (mm Hg)

Mean central venous pressure of cases studied was 8.84 ± 3.57 mm Hg.
Out of 60 cases enrolled 10 (16.7%) were having CVP between 0 to 5 mm Hg, 32 were having CVP between 6 to 10 mm Hg, 14 (23.3%) were having CVP between 11 to 15 mm Hg and 4 (6.7%) were having CVP between 16 to 20 mm Hg.

Table 2: Table depicting degree of association between the non-parametric variables.

(* = Significant)
(** = Very highly significant)

Correlations							
		AGE	BMI	e IVCD (cm)	i IVCD (cm)	IVCCI (%)	CVP(mm Hg)
AGE	Pearson Correlation	1	-0.256*	0.086	-0.026	0.153	0.227
	Sig. (2-tailed)		0.048	0.512	0.842	0.242	0.082
	N	60	60	60	60	60	60
BMI	Pearson Correlation	-0.256*	1	0.140	0.256*	-0.211	0.161
	Sig. (2-tailed)	0.048		0.285	0.049	0.105	0.219
	N	60	60	60	60	60	60
e IVCD (cm)	Pearson Correlation	0.086	0.140	1	0.737**	-0.007	0.550**
	Sig. (2-tailed)	0.512	0.285		0.000	0.955	0.000

	N	60	60	60	60	60	60
i IVCD (cm)	Pearson Correlation	-0.026	0.256*	0.737**	1	-0.662**	0.585**
	Sig. (2-tailed)	0.842	0.049	0.000		0.000	0.000
	N	60	60	60	60	60	60
IVCCI (%)	Pearson Correlation	0.153	-0.211	-0.007	-0.662**	1	-0.235
	Sig. (2-tailed)	0.242	0.105	0.955	0.000		0.071
	N	60	60	60	60	60	60
CVP(mm Hg)	Pearson Correlation	0.227	0.161	0.550**	0.585**	-0.235	1
	Sig. (2-tailed)	0.082	0.219	0.000	0.000	0.071	
	N	60	60	60	60	60	60

Table 3: Table showing Regression of CVP on i IVCD.

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	4.082	.945		4.318	.000	2.190	5.974
i IVCD (cm)	5.213	.949	.585	5.492	.000	3.313	7.113

Coefficient of correlation between i IVCD and CVP is 0.585.
P value of i IVCD is 0.000.
The regression of CVP on i IVCD is given by CVP = 4.08+5.21 × i IVCD

Table 4: Table showing Regression of CVP on e IVCD.

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	2.522	1.319		1.913	0.061	-0.118	5.162
e IVCD (cm)	4.143	0.826	0.550	5.014	0.000	2.489	5.797

Coefficient of correlation between e IVCD and CVP is 0.550. p value of e IVCD is 0.000. The regression of CVP on e IVCD is given by CVP = 2.52+4.14 × e IVCD

DISCUSSION

There has been much interest in using IVC diameter or caval index (CI) to predict the CVP. Many studies have focussed on the relationship between the IVC diameter and fluid volume and contradictory results have been declared.[1,7,8,9,10,11,12,13,14,15,16,17] We have tried to find out the exact degree of association between these parameters in our study done on 60 patients enrolled over a period of 12 months. The patients admitted in ICU or those scheduled for surgery with an indication of central line access who were spontaneously breathing were included. Out of 60 cases enrolled, 55% were males. Mean age of population was 52.12 ± 20.64 years. Our study group included the patients admitted to the ICU and OT planned for surgery who were breathing spontaneously, whereas study population in other researches included hemodialysis patients, patients with hemorrhagic shock due to trauma, patients during cardiac surgery and acutely ill children. We have excluded the patients on mechanical ventilation from our study because, there are many factors affecting the value of CVP other than blood volume, such as vascular tone, vasopressor therapy, cardiac performance, increased intra-abdominal or intrathoracic pressure.[18] CVP should be monitored in cases of shock, circulatory failure, massive infusion or transfusion requirement, situations with massive bleeding risk, situations where careful fluid resuscitation is a must such as in pediatric patients or patients with cardiac problems.[19] Our study included the patients in ICU admitted with shock, polytrauma, post op cases for ICU care and patients scheduled for gastrointestinal malignancy surgery or spine surgery. Mean CVP of the population, we studied was 8.84 ± 3.57 mm Hg with minimum CVP value of 2.96 mm of Hg and maximum CVP value of 17 mm of Hg. In our study, the mean IVCD during end expiration was 1.52 ± 0.47 cm and mean IVCD during end inspiration was 0.91 ± 0.4 cm. There was a significant difference between the mean diameter of IVC at the end of both phases of respiration in single cycle i.e. inspiration and expiration and both diameters were found to be significantly correlated with each other (R = 0.737, P = 0.000). These findings were in accordance with the study by Natori *et al.* done in 1979, which demonstrated that the lumen of IVC starts narrowing at the beginning of the inspiration, reaches the narrowest diameter at the end of inspiration and expands during expiration. These respiratory changes of inferior

vena cava diameter reverse during positive pressure ventilation due to increase in intrathoracic pressure.[20] The research of Feissel M and coworkers done in 2004 also confirm our findings. According to their study, IVC is affected by its phase of respiration. It collapses with decreased intrathoracic pressure during inspiration and expands with increased intrathoracic pressure during expiration.[21] Variations in IVCD depend not only on the compliance of the vessel but also on the amount of blood contained in the vessel, passive leg elevation, compliance of the right atrium and ventricle and right ventricular systolic function. Passive leg elevation is a reversible maneuver that mimics rapid fluid loading by shifting venous blood from the legs towards the intrathoracic compartment, thereby increasing right and left ventricular preloads. This results in increased blood pressure and cardiac output in coronary patients with a normal right ventricular ejection fraction.[22,23]Keeping this point in mind, we have taken the USG guided IVC parameters and corresponding CVP values in supine position, in order to avoid the bias. Mean age of the patients enrolled in our study was 52.12 $\pm$ 20.64 years with mean BMI of 20.72 $\pm$ 3.87 kg/m^2. These two parameters were found to have statistically significant negative correlation between each other (p value < 0.05). BMI was also found to be significantly correlated with i IVCD (p value < 0.05). The primary end point of this study was to examine the association between IVC and CVP. In this study we performed the bedside USG abdomen to measure e IVCD, i IVCD and IVCCI and tried to find out the degree of association between CVP measured through USG guided central venous access in right IJV and the IVC parameters. The resident performing the USG took demonstration classes from the co-guide (radiologist) and initial scannings were done under his supervision and rest of the scannings were recorded and cross checked by the radiologist for confirmation of accuracy before finalisation. In this study, the person who measured the CVP, the resident in Anaesthesia training who performed the bedside ultrasonography, and the patients were blinded to the data obtained by each other. The IVCCI was then calculated. Other ultrasound techniques like TTE and TEE can make similar assessments of fluid volume status.[16,17,18] but typically these require bedside transthoracic echocardiography and necessitate an increased level of expertise by the operator and a sedated or anaesthetised patient. In the present study we described a simple extension of a routinely taught component of clinical assessment using a tool (bedside USG), that is easy to use and mostly available in Anaesthesia Department. Measurements were made in real time and did not require elaborate or time consuming procedures such as multiple views or complicated techniques. In our study, a significant correlation between IVC diameters measured by ultrasonography at the end of expiratory and inspiratory phases of a single respiratory cycle and measured CVP values, was found in patients with spontaneous respiration. A highly significant positive correlation was between IVCD at end expiration and CVP (r=0.550, p=0.000) as well as between IVCD at end inspiration and CVP(r=0.585, p=0.000). Whereas a negative correlation was found between IVCCI and CVP but was not statistically significant (r= - 0.235, p=0.0-71). We derived the following formulas to measure the CVP of a spontaneously breathing patient using IVCD:

CVP = 4.08+5.21 × i IVCD

CVP = 2.52+4.14 × e IVCD

Thus, in patients with spontaneous breathing, IVC diameter measurement by non-invasive bedside ultrasonography method may provide an idea about CVP pressure and intravascular fluid deficit. These results are in conformity with various studies done by Nagdev AD *et al.*, Akilli B *et al.* and Corl K *et al.* which demonstrated that IVC diameter is not affected by compensatory vasoconstriction, which is the body's response to hypovolemia.[24, 25, 26]

Many studies have demonstrated clinical correlations between IVC measurements (collapsibility, absolute diameters) and traditional measures of intravascular volume status (central venous pressure), though a perfect linear correlation has yet to be demonstrated.[27,28,29.]

The IVCCI was calculated using the values of IVCD at the end of each phase of single respiratory cycle. The formula is:

$$\text{IVCCI} = \frac{\text{e IVCD} - \text{i IVCD}}{\text{e IVCD}} \times 100$$

Where IVCCI = Inferior vena cava collapsibility index

e IVCD = Inferior vena cava diameter at end expiration

i IVCD = Inferior vena cava diameter at end inspiration

The mean IVCCI of the patients in our study was 40.18 $\pm$ 18.40 %. Out of 60 cases enrolled

43 (71.7%) were having IVCCI of $\leq$50%, 16 (26.7%) were having IVCCI of >50% and only

1 patient (1.6%) was having IVCCI of zero.

IVCCI and i IVCD were negatively correlated with each other with a Pearson coefficient of -0.662 (p value = 0.000) and thus according to our experience IVCCI cannot be used as a reliable marker of CVP in spontaneously breathing patients.

As it was a time bound study , we could not categorise our patients into different groups as hypervolemic and normovolemic due to inadequate number of patients in each group, though our study has included patients with CVP values between as low as 2.96 mm of Hg and as high as 17 mm of Hg. This factor may be responsible for no correlation between CVP and IVCCI in our study.

The inferior vena cava is the biggest vein of venous system with low pressure. It is a high capacitance vessel. In volume depletion, it is easily collapsible with a smaller diameter. With fluid replacement, the collapsibility reduces and its diameter increases. In fluid overload, the vein's elasticity reaches a threshold of maximal distension and cannot collapse, and thus maintains a constant diameter.[25] In recent years, an increasing number of studies have compared CVP and the IVC diameter. In some of these studies, a significant correlation was found between the CVP and the IVC diameter, most evaluated EAP, while some did not detect such a correlation.[1,8,9,10,12,13] To conclude, According to our study, IVCD can be used as an alternative to CVP for intravascular fluid assessment in spontaneously breathing patients. But IVCCI cannot give the correct estimate of CVP and intravascular volume status.

SUMMARY AND CONCLUSION

This study aims to find the degree of association between CVP and IVC parameters i.e. i IVCD, e IVCD and IVCCI. 60 patients with an indication of central venous catheterisation who were scheduled for surgery or admitted in ICU over a period of 12 months were enrolled for the study. After written informed consent central line secured in right IJV and CVP transduced. At single point of time diameter of IVC measured at the end of inspiration and expiration by freezing the image on Sonosite Micromax portable USG machine using 3-5 MHz curvilinear probe by the resident and the corresponding CVP value of the patient from monitor was noted by the other person in OT or ICU. IVCCI was calculated for each patient using the formula given below:

$$\text{IVCCI} = \frac{\text{e IVCD} - \text{i IVCD}}{\text{e IVCD}} \times 100$$

Master chart from the data was made in MS excel 2010 and statistical analysis done using SPSS Microsoft software and the results were as follows: Very highly significant correlation between CVP and i IVCD was found.(p value < 0.001). Regression formula is CVP= (4.08+5.21 × i IVCD). Very highly significant correlation was found between CVP and e IVCD. (p value < 0.001). Regression formula is CVP= (2.52+4.14 × e IVCD). There was a negative correlation between CVP and IVCCI but was not statistically significant. (p value > 0.05)

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