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Correlation of ultrasound guided measurement of inferior vena cava diameter to central venous pressure to assess the volume status of intensive care unit patients

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Abstract

Background: Assessment of intravascular volume status is an essential parameter for the diagnosis and management of critically-ill patients. In order to assess the intravascular volume status noninvasively, we conducted a study to to find the correlation, if any, between sonographic IVC collapsibility index and Central Venous Pressure to assess the volume status in ICU patients.

Methods: The Institutional Ethics Committee approval was obtained. 60 spontaneously breathing post-operative patients with a functioning central venous catheter were recruited for this study. The distal port of the catheter was connected to a pressure transducer and the pressure displayed on the monitor in mmHg was noted. Simultaneously the IVC diameters during end inspiration and end expiration were measured in the longitudinal and transverse orientations using the M-mode of the ultrasound machine. The Collapsibility Index was calculated from the IVC diameters. Collapsibility Index? 50% suggested hypovolemia and Collapsibility Index <50% suggested euvolemia or hypervolemia. This was compared with the measured Central Venous Pressure to find the correlation between the two. Additionally the change in IVC diameter with Central Venous Pressure was observed. The IVC Collapsibility Index for longitudinal and transverse orientations were calculated separately and they were compared with each other to find which among them correlated the best with the Central Venous Pressure.

Results: In our study the IVC Collapsibility Index correlated well with the Central Venous Pressure. The sensitivity and specificity of IVC Collapsibility to Central Venous Pressure were also found to be statistically significant. The change in IVC diameters were also found to be statistically significant when compared to Central Venous Pressure. The sensitivity of the IVC Collapsibility Index in the longitudinal orientation was much better than that of the transverse orientation to detect low CVP.

Conclusion: IVC Collapsibility Index can be used as an alternative to CVP measurement to guide us in the fluid management of patients in the ICU.

Keywords: Ultrasound, IVC diameter, IVC collapsibility index, CVP

Introduction

Fluid management in the perioperative period plays a pivotal role in the recovery of the patient. Hypovolemia with inappropriate use of vasopressors to maintain the blood pressure reduces the organ perfusion leading to ischemia.(1) On the other hand overzealous fluid replacement causes cellular swelling and congestion of lungs thereby increasing morbidity and mortality.(2)

Central venous pressure: Central venous catheters have a wide variety of uses such as hemodynamic monitoring, drug administration, total parenteral nutrition, trans-venous pacemaker placement, pulmonary artery catheterization etcetera.(3)

The CVP is a static measure of volume.(4) This method has been followed widely to assess the volume status and thereby treating the patient accordingly. Insertion of central venous catheter is contraindicated when the patient has a very low platelet count, any coagulation disorders, infection over the insertion site etc. There have been reports of many complications with a central venous catheter like infections, accidental arterial puncture, hematoma, hemothorax, pneumothorax, air embolism, dysrhythmias.(5) If the catheter tip is not in position there might be damping or overshooting of the CVP.

Ultrasound: Recently the ultrasound guided measurement of the IVC diameter and its changes with respiration have been used to calculate the fluid status of a patient. It is a safe technique and it is also relatively cheap. It can be used as an alternative to central venous catheterization to assess the volume status of patients. It is a dynamic measure of intravascular volume status, as it reflects the volume changes that take place with respiration.

The IVC adjusts to the body's volume status by changing its diameter depending on the total body fluid volume. The caval opening increases in size during inspiration, which encourages venous return of blood to the heart through the IVC due to the negative intra-thoracic pressure. This results in the collapse of the IVC. During expiration the reverse happens, where due to the positive intra-thoracic pressure the pressure gradient decreases causing a distension of the IVC.(14)

The liver parenchyma can be used as an acoustic window to view the IVC apart from the routine subxiphoid view. IVC measures 1.5-2.5cm in diameter which varies with inspiration, expiration and also with the patient’s volume status. A diameter of <1cm indicates hypovolemia, whereas >2.5cm suggests fluid overload.[6]

The right hepatic vein is the last tributary of the IVC in the abdomen. This is an important landmark in the visualization of the IVC by ultrasound as the diameter of the IVC is to be measured just distal to the junction of the right hepatic vein with the IVC so that the intra-abdominal diameter is measured and not the intra-thoracic diameter of the IVC as this measurement can result in fallacies due to the intra-thoracic pressure.[7]

The main aim of the study was to find a correlation, if any, between bedside ultrasound guided measurement of the inferior vena cava collapsibility to central venous pressure. The other objectives were:

1. To correlate the various diameters of the IVC to CVP and to find the diameter that correlates the most with CVP.
2. To establish IVC collapsibility index as an effective alternative to CVP for perioperative fluid management.

Methods

60 patients of both sex admitted in the PACU, SRM Medical College Hospital & Research Centre, who had a functioning central venous catheter inserted via the IJV for any clinical indication, aged between 18 and 80, were involved in this single blinded Correlational study. The study patients included were post-operative patients who had undergone surgeries like elective and emergency laparotomies (bowel perforation/obstruction, splenectomies, gastrectomy, radical cystectomies, Whipples procedure etc.), craniotomies for intracranial SOL excision, etc. Patients with any cardiac abnormality, history of chest injury, patients being mechanically ventilated, patients with poor echo window due to distended abdomen, patients with non-sinus rhythm, pregnant and lactating women were excluded from the study.

The Institutional Ethics Committee approval was obtained. The procedure was explained to the patient and informed consent was obtained. A baseline echocardiogram was done by the cardiologist to rule out any cardiac abnormality. Patients were made to lie supine, with the bed flat. The basic monitors (ECG, NIBP and SpO_2) were attached. The vital parameters were stable for the patients during the study.

Measurement of the CVP: The transducer used to measure the central venous pressure was fixed at the level of the patient's phlebostatic axis, the level at which the fourth intercostal space meets the mid-axillary line. The transducer was connected to the monitor using its cable. After zeroing, the transducer was left open to the central venous catheter. CVP waveform was displayed on the monitor with the average central venous pressure measured in mmHg. This provided a means to measure the CVP continuously.

This measurement was taken by another anesthesiologist and the principal investigator was blinded to this value.

Measurement of the IVC diameters using USG: The patient was maintained in the same position after measurement of the CVP and the IVC caliber was measured using an ultrasound probe. The 3s (low frequency high penetration) probe was used at the level of the subxiphoid region. The in-plane view of the USG probe showed the IVC in its longitudinal axis draining into the right atrium. The right hepatic vein, the last tributary to join the IVC intra-abdominally was visualized in this view.

The respiratory changes are reflected in the IVC caliber. After confirming the IVC using the PW mode, the 'Motion' mode (M) is used to select a plane just distal to the right hepatic vein. This was to make sure the IVC caliber was measured intra-abdominally avoiding the intra-thoracic region and also for standardization. The 'M' mode displays changes in diameter at that section of the IVC. The effect of respiration is noted as changes in the diameter of the IVC which is measured. During inspiration the intra-thoracic pressure is negative thereby sucking in of blood from the IVC causing the IVC to collapse and the vice versa during expiration. The maximum and minimum diameters are noted.

The same was done in the out-of-plane view of the USG probe as well which showed the IVC and the aorta in their transverse axes. IVC and aorta were differentiated using the 'PW' mode and then the IVC diameters measured using the 'M' mode.

The average of the expiratory and inspiratory diameters of the IVC in the longitudinal and transverse orientations were calculated and they were used to calculate the Collapsibility Index of the IVC.[26]

$$\text{Collapsibility Index (CI)} = \frac{\text{Exp. diameter of IVC} - \text{Insp. diameter of IVC}}{\text{Exp. diameter of IVC}} \times 100$$

The caval index is expressed as a percentage, where one end of the spectrum is 0% which indicates minimal collapse of the IVC meaning volume overload and the other end of the spectrum is 100% which indicates almost complete collapse of the IVC meaning volume depletion.

Results

Data Analysis: The patients were divided into two groups by CVP $\leq$ 8 mm Hg and > 8 mm Hg. Descriptive statistics was done for all data and were reported in terms of mean values and percentages. Suitable statistical tests of comparison were done. Continuous variables were analysed with the unpaired t test and ANOVA. Categorical variables were analysed with the Chi-Square Test and Fisher Exact Test. Pearson's product–moment correlation coefficients were used to analyze the correlation coefficients. The correlation of the caval index and CVP was reported as sensitivity and specificity. Statistical significance was taken as P < 0.05. The data was analysed using SPSS version 16 and Microsoft Excel 2007.

End Inspiration Transverse Orientation

Table 1

End Inspiration Transverse Orientation (mm)	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
≤ 5 mm	15	68.18	0	0.00
6-10 mm	4	18.18	22	57.89
11-15 mm	2	9.09	12	31.58
16-20 mm	1	4.55	3	7.89
> 20 mm	0	0.00	1	2.63
Total	22	100	38	100

End Inspiration Transverse Orientation (mm)	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	4.99	10.36
SD	4.11	4.64
P value Unpaired t Test		0.0000

In patients belonging to CVP ≤ 8 mm Hg and CVP > 8 mm Hg group, the mean end inspiration transverse orientation measurement were 4.99 mm and 10.36 mm respectively and their difference were statistically significant as the p value is 0.0000 as per unpaired t-test. So the mean end inspiration transverse orientation measurement significantly increases as CVP increases.

End Expiration Transverse Orientation

Table 2

End Expiration Transverse Orientation (mm)	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
≤ 10 mm	9	40.91	5	13.16
11-20 mm	12	54.55	29	76.32
21-30 mm	1	4.55	3	7.89
31-40 mm	0	0.00	1	2.63
Total	22	100	38	100

End Expiration Transverse Orientation (mm)	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	11.59	14.51
SD	4.30	4.70
P value Unpaired t Test		0.0181

In patients belonging to CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group, the mean end expiration transverse orientation measurement were 11.59 mm and 14.51 mm respectively and their difference were statistically significant as the p value is 0.0181 as per unpaired t- test. So the mean end expiration transverse orientation measurement significantly increases as CVP increases.

End Inspiration Longitudinal Orientation

Table 3

End Inspiration Longitudinal Orientation (mm)	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
≤ 5 mm	18	81.82	6	15.79
6-10 mm	3	13.64	16	42.11
11-15 mm	1	4.55	12	31.58
16-20 mm	0	0.00	3	7.89
> 20 mm	0	0.00	1	2.63
Total	22	100	38	100

End Inspiration Longitudinal Orientation (mm)	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	4.25	9.84
SD	2.18	4.76
P value Unpaired t Test		0.0000

In patients belonging to CVP ≤ 8 mm Hg and CVP > 8 mm Hg group, the mean end inspiration longitudinal orientation measurement is 4.25 mm and 9.84mm respectively and their difference were statistically significant as the p value is 0.0000 as per unpaired t- test indicating. So the mean end inspiration longitudinal orientation measurement significantly increases as CVP increases.

End Expiration Longitudinal Orientation

Table 4

End Expiration Longitudinal Orientation (mm)	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
≤ 10 mm	6	27.27	7	18.42
11-20 mm	16	72.73	27	71.05
21-30 mm	0	0.00	3	7.89
31-40 mm	0	0.00	1	2.63
Total	22	100	38	100

End Expiration Longitudinal Orientation (mm)	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	11.57	14.79
SD	3.09	5.25
P value Unpaired t Test		0.0041

In patients belonging to CVP ≤ 8 mm Hg and CVP> 8 mm Hg group, the mean end expiration longitudinal orientation measurement is 11.57 mm and 14.79mm respectively and their difference were statistically significant as the p value is 0.0041 as per unpaired t- test. So the mean end expiration longitudinal orientation measurement significantly increases as CVP increases.

Caval Index

Table 5

Caval Index	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
< 25 %	0	0.00	10	26.32
25-49%	4	18.18	27	71.05
50-74%	15	68.18	1	2.63
≥ 75 %	3	13.64	0	0.00
Total	22	100	38	100

Caval Index(%)	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	61.87	32.41
SD	13.40	9.95
P value Unpaired t Test		0.0000

In patients belonging to CVP ≤ 8 mm Hg group and CVP> 8 mm Hg group, the mean caval index measurement is 61.87% and 32.41% respectively and their difference were statistically significant as the p value is 0.0000 as per unpaired t- test. So the mean caval index measurement significantly decreases as CVP increases.

Caval Index Vs CVP

Table 6

Caval Index Vs CVP	CVP ≤ 8 mm Hg	CVP > 8 mm Hg	Column Total
CI ≥ 50%	19	1	20
CI < 50%	3	37	40
Row Total	22	38	60

Caval Index Vs CVP – Accuracy Statistics	
Sensitivity	86.40%
Specificity	97.40%
Positive Predictive Value	95.00%
Negative Predictive Value	92.50%
Likelihood Ratio +ve	32.82
Likelihood Ratio -ve	0.14
Prevalence	0.37
Test Score%	93.33

The above table indicates that the diagnostic effectiveness or diagnostic accuracy is very high. It means that the overall value of caval index in detecting low CVP as a combined screening and confirmatory case-finding test is good.

Transverse Caval Index

Table 7

Transverse Caval Index	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
< 25%	0	0.00	15	39.47
25-49%	5	22.73	23	60.53
50-74%	13	59.09	0	0.00
≥ 75%	4	18.18	0	0.00
Total	22	100	38	100

Transverse Caval Index	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	60.67	30.07
SD	18.24	10.26
P value Unpaired t Test		0.0000

In patients belonging to CVP ≤ 8 mm Hg and CVP>8mmHg group, the mean transverse caval index measurement were 60.67% and 30.07% respectively and their difference were statistically significant as the p value is 0.0000 as per unpaired t-test. So the mean caval index measurement significantly decreases as CVP increases.

Transverse Caval Index Vs CVP

Table 8: Transverse Caval Index Vs CVP

Transverse Caval Index Vs CVP	CVP ≤ 8 mm Hg	CVP > 8 mm Hg	Column Total
CI ≥ 50%	17	0	17
CI < 50%	5	38	43
Row Total	22	38	60

Transverse Caval Index Vs CVP – Accuracy Statistics	
Sensitivity	77.3%
Specificity	100.0%
Positive Predictive Value	100.0%
Negative Predictive Value	88.4%
Likelihood Ratio +ve	0.00
Likelihood Ratio -ve	0.23
Prevalence	0.37
Test Score%	91.67

Longitudinal Caval Index

Table 9: Longitudinal Caval Index

Longitudinal Caval Index	CVP ≤ 8 mm Hg Group	%	CVP > 8 mm Hg Group	%
< 25%	0	0.00	9	23.68
25-49%	2	9.09	25	65.79
50-74%	17	77.27	3	7.89

≥ 75%	3	13.64	1	2.63
Total	22	100	38	100

Longitudinal Caval Index	CVP ≤ 8 mm Hg Group	CVP > 8 mm Hg Group
N	22	38
Mean	64.02	34.94
SD	11.28	13.79
P value Unpaired t Test		0.0000

In patients belonging to CVP ≤ 8 mm Hg and CVP>8mmHg group, the mean caval index measurement is 64.02% and 34.94% respectively and their difference were statistically significant as the p value is 0.0000 as per unpaired t-test. So the mean caval index measurement significantly decreases as CVP increases.

Longitudinal Caval Index Vs CVP

Table 10: Longitudinal Caval Index Vs CVP

longitudinal Caval Index Vs CVP	CVP ≤ 8 mm Hg	CVP > 8 mm Hg	Column Total
CI ≥ 50%	20	5	25
CI < 50%	2	33	35
Row Total	22	38	60

Longitudinal Caval Index Vs CVP – Accuracy Statistics	
Sensitivity	90.9%
Specificity	86.8%
Positive Predictive Value	80.0%
Negative Predictive Value	94.3%
Likelihood Ratio +ve	6.91
Likelihood Ratio -ve	0.10
Prevalence	0.37
Test Score%	88.33

By comparing the caval indices in the longitudinal and transverse views we can see that

- The sensitivity is more in the longitudinal view
- The specificity is more in the transverse view
- The positive predictive value is more in the transverse view
- The negative predictive value is more in the longitudinal view
- The overall accuracy is more in the transverse diameter than the longitudinal view

Discussion

Correlation between Caval index and CVP: In our study there is a strong positive correlation between caval index and decrease in CVP. This is indicated by the Pearson's R Correlation value of -0.740627 with p = 0.0000 meaning that the increase in caval index due to low CVP is true 74% of times. It also showed a sensitivity of 97.40% and specificity of 86.40% for the IVC-CI to correlate with CVP. The positive predictive value for the same was found to be 92.50% and the negative predictive value was found to be 95.00%.

Panita Worapratya[8] and associates in their study on 30 subjects concluded using the Pearson's product–moment correlation coefficient that there was good correlation between IVC-CI and CVP with the Pearson's R Correlation value of −0.721 (p=0.000) by two-dimensional mode ultrasound and −0.647 (P=0.001) by M-mode. This study has shown similar results to our study.

Peter Stawicki[9] et al have conducted a similar study on 124 patients, but their study showed a statistically significant but weak negative correlation between IVC-CI and CVP with Pearson's R Correlation value of -0.315 with p = 0.007. This is in contrast to our study and might be due to a high proportion (45%) of mechanically ventilated patients in their study. Mechanical ventilation alters the entire physiology of the IVC's diameter change with respiration, as there is a positive intra-thoracic pressure during inspiration causing the IVC to expand and vice versa during expiration.

The study by Marcelino P[10] and colleagues on 477 patients admitted in the ICU arrived at a conclusion that statistically significant correlation was found between the following parameters: an IVC index < 25% and a CVP > 13 mmHg; an IVC index and a CVP 26%-50%; an IVC index > 51% and CVP < 7 mmHg.

Relationship between IVC diameter and CVP: In our study it has been found that the IVC diameter increases as the CVP increases. Also the expiratory diameters are more compared to the inspiratory diameters, which is attributed to the changes in the intra-thoracic pressure.

There is an average increase of 5.37mm diameter in the end inspiratory transverse diameter in the group with CVP > 8 mmHg compared to the group with CVP ≤ 8 mmHg. Similarly in the end expiratory transverse orientation there is a 2.92mm increase in the CVP > 8 mmHg group compared to the CVP ≤ 8 mmHg group. This shows that the increase in diameter of the IVC in the transverse orientation is directly proportional to the increase in CVP in spontaneously breathing individuals.

In the longitudinal orientation too the findings were similar with the diameters increasing by 5.60mm and 3.22mm in the end inspiratory longitudinal orientation and end expiratory longitudinal orientations respectively in the CVP > 8mmHg group compared to the CVP ≤ 8mmHg group. This shows that the longitudinal diameter of the IVC increases proportionally to the CVP in spontaneously breathing individuals.

Wiwatworapan W[11] and colleagues in their study comparing IVC diameter and CVP in critically ill patients found the IVC diameter to be ≤ 10 mm for patients with a CVP around 10 cm H_2O and they found it to be 77% sensitive and 91% specific. They also showed that the IVC diameter increased to 15 mm when the CVP increased to 15 cm H_2O and this was shown to have a sensitivity of 90% and a specificity of 89%. Our study has had similar results as the diameter increase has been proven to be statistically significant.

In the study conducted by Citilcioglu S[12] and allies' significant relationship was found between the IVC diameters measured during end expiratory and end inspiratory phases and CVP with p values of 0.002 and 0.001 respectively, in the patients breathing spontaneously. In the patients on mechanical ventilator there was no statistical significance between IVC diameter and CVP.

Transverse Vs Longitudinal orientations: The transverse diameter of the IVC was found to correlate with CVP with a sensitivity and specificity of 77.3% and 100%. This implies that the transverse measurement of the IVC would predict a low or high CVP accurately by 77.3%. But it would never predict a low CVP to be high and vice versa.

The longitudinal diameter of the IVC was also found to correlate well with CVP with its sensitivity and specificity being 90.9% and 86.8%.

These values show that the longitudinal diameter is more sensitive, in other words it is much unlikely to miss a low CVP or hypovolemic states. It is also shown that the specificity of the longitudinal orientation is 86.8% compared to the 100% by transverse orientation implying that the longitudinal orientation has a slight chance of predicting low CVP for a euvolemic patient.

De Lorenzo RA[13] and colleagues did a study on 72 subjects and they calculated correlational coefficients for longitudinal and transverse orientations separately at three levels. The subxiphoid, midpoint and supra-iliac. They found that the longitudinal orientations had better correlation with CVP than the transverse orientations with correlational coefficients of 0.49, 0.51 and 0.50 at those three levels as opposed to 0.42, 0.38 and 0.67 respectively.

Hence in an emergency when only one orientation of the IVC can be measured, it is better to visualize the longitudinal orientation due to its higher sensitivity.

Conclusion

The inferior vena cava collapsibility index can be used as a non-invasive alternative to the CVP measurement, which has been the gold standard to assess the volume status in ICU patients. It is less time consuming and also eliminates the complications associated with central venous catheter insertion. Also the longitudinal diameter of the IVC correlates better with CVP than the transverse diameter.

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