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Research Article

ULTRASONOGRAPHIC MEASUREMENT OF RESPIRATORY VARIATION IN INFERIOR VENA CAVA DIAMETER AND COLLAPSIBILITY INDEX AND ITS CO-RELATION TO FLUID CHALLENGE, PASSIVE LEG RAISING AND CVP

Alpana kaistha, Anjna badhan, Surinder Singh, and Sonali Kaushal

Department of Anaesthesia and Critical Care; IGMC, Shimla

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ABSTRACT

Objective: The objective of our study was to assess the correlation of ultrasound guided measurement of respiratory variation in inferior vena cava diameter (IVCD) and its collapsibility index (IVCCI) and its correlation to fluid challenge, passive leg raising (PLR) and CVP (CVP) in critically ill patients.

Methods: Forty adult patients admitted in intensive care unit over a period of twelve months between 18-60 years, of age with central venous catheter in situ and were spontaneously breathing and having accessible epigastric region for ultrasonography were included in the study. A Sonosite Micromax ultrasonographic machine was used for all examinations. IVC diameter measurements were recorded in centimeters with help of ultrasonography both at end-inspiratory and end-expiratory at baseline (T0), 5 min after PLR (TPLR1), 5minute after rebound(TR1), 15mins after saline infusion (TS), 5min after passive leg raising (TPLR2), 5mins after rebound (TR2) and simultaneously corresponding CVP value was recorded at each point of time. A paired sample t-test was used to compute the p-values.

Results: The total number of patients enrolled was 40 (100%). In our study, both PLR and fluid challenge has positive significant effect on CVP values. A highly significant correlation was found between inferior vena cava diameter both inspiratory and expiratory and CVP. There was a statistically significant positive correlation between eIVCD and iIVCD. Results of our study show a cut-off value for CVP as 10cmH2O with respect to IVCCI of 50%. There is a negative correlation between inferior vena cava collapsibility index and CVP value and results of correlation were not statistically significant when CVP value < 10cmH2O and after saline infusion, negative correlation between IVCCI and CVP value persisted and became statistically significant when CVP was more than 10cmH2O. Also when CVP value was < 10cmH2O, the inferior vena cava collapsibility index was >50%. After saline infusion when CVP >10cmH2Othere was decrease in collapsibility of inferior vena cava <50%.

Conclusion: There is a positive correlation of IVC diameters in both phases of respiration after PLR and fluid loading. IVC diameters can be measured easily and in ICU patients can be used for fluid volume assessment. IVCCI is also easily calculated and can be used for assessment of fluid volume status and response to fluid therapy.

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INTRODUCTION

Optimal fluid management is crucial in the treatment of critically ill patients.[1] Too little fluid administration may result in tissue hypo perfusion and worsen oxygen delivery, whereas, over-prescription of fluid also appears to impede oxygen delivery and compromise patient outcome.[2] The postural manoeuvres or infusion of small amounts of fluids lead to change in preload which changes cardiac output. The dynamic indices are based on the changes in cardiac output or stroke volume. Therefore, "dynamic indices" such as PLR (PLR) test and fluid challenge have been introduced to replace "static" markers.[3] PLR increases venous return and effective circulating volume. PLR non-invasively delivers a fluid challenge of around 300mL to the central circulation, allowing assessment of fluid responsiveness without fluid administration. The

Corresponding author:* **Alpana kaistha
Department of Anaesthesia and Critical Care; IGMC, Shimla

normal CVP in an awaken patient is 1-7mmHg.[4] CVC insertion has been invasive, time consuming and has potential complications and risks.[5]Central venous catheterization however, may be associated with various complications like arterial puncture, hematoma, hemothorax, pneumothorax, nerve injuries, air embolism, arrhythmias, lymphatic system injury and sepsis.[4] Recently, bedside point of care, ultrasonography (USG) has gained popularity in the assessment of volume status. Its advantages include non-invasiveness; rapid diagnosis and objectivity, reproducibility and adequate fluid management.[1]

Ultrasound guided IVCD and inferior vena cava collapsibility index (IVCCI) can be used as fast, reliable and non-invasive method of fluid assessment and responsiveness that too without having the risk of complications associated with central venous catheter. Also this can be method of choice in uncooperative patients, paediatric patients or in patients with bleeding disorders where central venous access is contraindicated.

MATERIAL AND METHODS

The present study was conducted in the Intensive Care Unit of, I. G. M. C, Shimla in the Department of Anesthesiology after the approval of institutional ethics committee. All the patients in the hospital intensive care unit (ICU), between 18-60 years, of age with central venous catheter in situ and were spontaneously breathing and patients with accessible epigastric region for USG were included in the study and the patient refusal, patient on mechanical ventilation, patient with right para-median incision in upper abdomen, patients of acute respiratory distress syndrome, patients of heart failure, left ventricle dysfunction, valvular heart disease, myocardial infarction, any contraindication to CVC, any contraindication to PLR e.g. lower limb or pelvic trauma. Patient's demographic data included age, sex, weight, height, body mass index (BMI), biochemical tests and hemogram.

All patients were placed in supine position for baseline measurements. The mean arterial pressure (MAP), heart rate (HR) oxygen saturation (SpO_2) and CVP (CVP) were recorded. USG imaging was performed by using Sonosite Micromax USG machine. Low frequency (2-5 MHz) curvilinear probe was used to measure the IVCD's during end-inspiration and end-expiration. Inferior vena cava diameter (IVCD in centimeter) and inferior vena cava collapsibility index (IVCCI in percentage) was measured in lying down supine position at level of hepatic vein with the help of USG at baseline. The probe was placed longitudinally just below the xiphoid process scanning of the IVC going into right atrium by moving the probe 1-2cm to right of midline was done. After determining the junction of hepatic veins with IVC, the antero -posterior (AP) diameter of IVC will be measured approximately 2cm caudal to inflow of hepatic veins.

The bed was maneuvered to achieve passive leg raising (PLR) of 30^0. Blood pressure values, HR, IVC diameters and CVP values were recorded after five min after PLR .The patient was returned to baseline position and parameters were recorded again after 5min and mentioned as rebound. A fluid challenge was given with normal saline or ringer lactate either 30ml/kg body weight or till CVP of $12cmH_2O$ is achieved whichever occurred first. CVP was also recorded simultaneously.

All parameters were recorded after 15minute of fluid infusion. The bed was again maneuvered to achieve PLR of 30^0 and all parameters were again recorded after 5min. The patient was again returned to normal supine position and all parameters were recorded again. The IVC collapsibility index was calculated by equation given below and was compared with the corresponding CVP values, that is, baseline, after PLR and after fluid loading.

$$\text{IVCCI} = \frac{\text{eIVCD} - \text{iIVCD}}{\text{eIVCD}} \times 100$$

Where, IVCCI = Inferior vena cava collapsibility index
eIVCD = Inferior vena cava at end-expiration
iIVCD = Inferior vena cava at end-inspiration

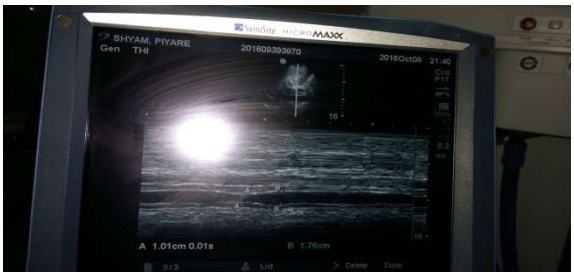


Fig 3 Inferior vena cava diameters on ultrasonograpghy.

RESULTS

The total number of patients enrolled was 40 (100%). Out of 40 cases 16 (40%) were females and 24 (60%) were males. The mean age of the patients was 41.1±12.9 years while median age was 40.00 years. There was increase in heart rate after all manoeuvres and these all showed statistically significant result when compared with baseline (T_0) with p value (0.00). And there was also increase in mean arterial pressure and result was statistically significant.

In our study, the base line CVP value was 8.10 ± $0.49cmH_2O$ and after saline infusion of 30 ml/kg maximum was 12.65 ± 1.36cmH2O. After PLR, (T_{PLR1}) the mean CVP value was 9.45 ± 0.67cmH2O and it was found that PLR has significant increase in value of CVP from baseline and the mean increase after PLR was 1.35cmH2O (p value 0.00). After saline infusion, the mean CVP measured was 11.65 ± 0.86cmH2O and increase was significant from baseline (p value 0.00). The increase from baseline was 3.55cmH2O. Both PLR and fluid challenge has positive significant effect on CVP values which implied that increase in volume with either after PLR or after fluid loading will lead to increase in CVP value of patient.

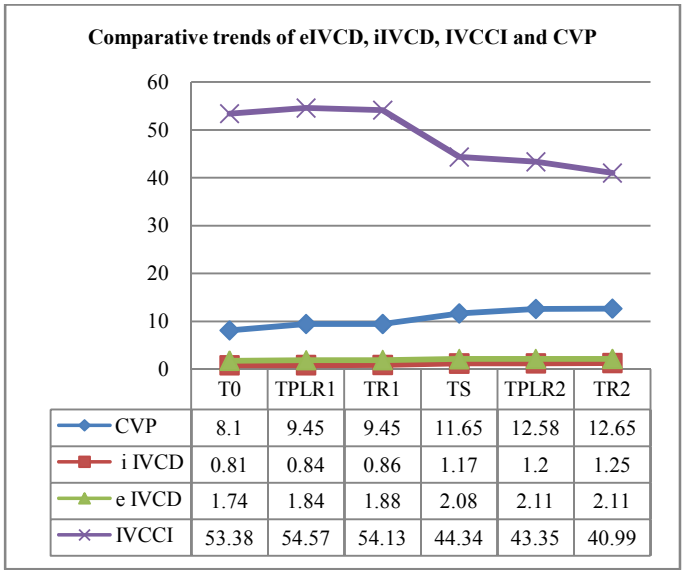
The mean IVCD during end inspiration at baseline (T_0) was 0.81 ± 0.18cm. There was increase in end inspiratory IVCD after PLR and saline infusion and results were significant from baseline. The mean value of end inspiratory diameter after PLR (T_{PLR1}) was 0.84 ± 0.14cm and mean value after saline infusion (T_S) was 1.17 ± 0.34cm.

The mean end expiratory diameter of IVC at baseline (T_0) was 1.74±0.35cm and there was significant increase in expiratory diameter of IVC after various study manoeuver in our study. The mean values of eIVCD after PLR and after saline infusion were 1.84 ± 0.31cm and 2.08 ± 0.29cm. The mean increase from baseline after PLR T_{PLR1} was 0.1cm and after saline (T_S)

was 0.34cm which was statistically significant (with p value 0.00).

There was a significant difference between the mean diameter of IVC at the end of both phases of respiration in a single cycle, and both diameters were found to be significantly correlated with each other (R value = 0.972 at T_0). After PLR (T_{PLR1}), there was statistically significant positive correlation between iIVCD and eIVCD (R value=0.329). In our study, inspiratory diameter and expiratory diameters of IVC after PLR and saline infusion positively correlated with each other and values were statistically significant (p value 0.00) in both phases of respiration.

The mean IVCCI at base line was 53.38 ± 2.6% and after PLR its value was 54.57 ± 4.23%. The IVCCI at T_0-T_{PLR1} and T_0-T_{R1} there was positive correlation but these were not significant results. The IVCCI values decreased after saline infusion (44.34 ± 12.90%), 5 min after PLR (43.35 ± 14.68%) and 5min after rebound (40.99 ± 15.79%) and were statistically significant in relation to baseline (p value 0.00).There was a negative correlation found between IVCCI and CVP at baseline T_0, T_{PLR1} and T_{R1} and also results were not statistically significant. After 15 min of saline infusion T_S, T_{PLR2} and rebound T_{R2} there was negative correlation between IVCCI and CVP and also results were statistically significant. In our study, when the CVP values between 8-10cmH2O i.e. mean values at T_0, T_{PLR1}, T_{R1} (8.10 ± 0.49, 9.45 ± 0.67 and 9.45 ± 0.67cmH2O) the corresponding IVCCI values are >50% i.e. 53.38 ± 2.6%, 54.57 ± 4.23% and 54.13 ± 3.65%. When CVP values increased above 10cmH2O i.e. after saline infusion T_S, T_{PLR2}, T_{R2} the IVCCI values decreased to <50% i.e. 44.34 ± 12.90%, 43.35 ± 14.68%, 40.99 ± 15.79%.



	T0	TPLR1	TR1	TS	TPLR2	TR2
CVP	8.1	9.45	9.45	11.65	12.58	12.65
i IVCD	0.81	0.84	0.86	1.17	1.2	1.25
e IVCD	1.74	1.84	1.88	2.08	2.11	2.11
IVCCI	53.38	54.57	54.13	44.34	43.35	40.99

DISCUSSION

There has been much interest in using inferior vena cava diameter (IVCD) or caval index (CI) to predict the CVP (CVP).[4] We have tried to find out the exact degree of association between inferior vena cava collapsibility index (IVCCI), both inspiratory and expiratory variation in IVCD and their correlation to fluid challenge, PLR and CVP. Central venous pressure is a value indicating right atrial pressure (RAP) or right ventricular filling pressure. In normal humans, changes in CVP correlate with changes in left ventricular filling pressure. CVP is only measure of cardiac preload when utilized as a dynamic parameter and is related to cardiac output or a surrogate of it. CVP measurements are relatively easy to obtain, however, it is an invasive procedure and is associated with a number of complications.Also 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 intra-thoracic pressure.[6]

In normal humans, change in CVP has been correlated well with changes in left ventricular filling pressure. There are many factors affecting the value of CVP, such as cardiac performance, blood volume, vascular tone, increased intra-abdominal or intra-thoracic pressure and vasopressor therapy. In our study we included spontaneously breathing patients in recovery phase and all such factors were presumably in normal range.

Central venous catheter placement is invasive procedure and has risk of complications both early and late. In addition to complications, there are other disadvantages such as increase in health care cost, risk of microbial colonisation, sepsis, prolonged hospitalisation and reduced quality of life. Also the procedure requires a level of technical expertise. Due to all these reasons, the use of a reliable non-invasive bed side method for the assessment of fluid volume status is needed.

The inferior vena cava is the biggest vein of venous system with low pressure and variability in its diameter reflects venous pressure changes to certain extent. The intravascular volume change is also reflected by change in size of vein. For this reason, the inferior vena cava diameter may be important tool in evaluation of hypovolemia and hypervolemia due to easy accessibility.[7]

Diameter of inferior vena cava changes with respiration and total body fluid.[8,9]In our study, the patients were spontaneously breathing and inferior vena cava diameter was measured in both phases of respiration and there was significant increase in both end inspiratory and end expiratory IVCD after all the manoeuvres and results were significantly higher from baseline. This trend of increase in IVCD was accompanied by increase in CVP and showed a positive correlation of increase in iIVCD and eIVCD. These findings were in accordance with study by Natori *et al.*(1979)[10], which demonstrated that the lumen of inferior vena cava starts narrowing at beginning of inspiration, reaches the narrowest diameter at the end of inspiration and expands during expiration. These respiratory changes on inferior vena cava diameter are reversed during Valsalva manoeuvre and positive pressure ventilation due to increase in intra-thoracic pressure. The study of Feissel M *et al.* (2004)[11] also confirms our findings. According to their study, inferior vena cava diameter is affected by the phases of respiration. It collapses with decreased intra-thoracic pressure during inspiration and expands with increased intra-thoracic pressure.

Variation in IVCD depends not only on compliance of vessel but also on the amount of blood contained in the vessel, passive leg elevation, compliance of right atrium and right ventricular systolic function. Passive leg elevation is a reversible

manoeuvre that mimics rapid fluid loading by shifting venous blood from legs towards the intra-thoracic compartment, thereby increasing right and left ventricular preload and results increase in blood pressure and cardiac output in patients with normal right ventricular ejection fraction.[12,13]

In our study, a significant correlation between inferior vena cava diameter as measured by transabdominal ultrasonography at the end of expiratory and inspiratory phases of a single respiratory cycle and measured CVP values, were found in patients who were spontaneously breathing.

In our study, the cut off value of IVVCI was 50% for correlation with PLR, saline infusion and CVP. Our study showed a negative correlation between IVCCI and CVP at all the measurements but at baseline T_0, T_{PLR1} and T_{R1} results were not statistically significant. After 15min of saline infusion (T_S), 5min after PLR (T_{PLR2}) and rebound (T_{R2}) there was negative correlation between IVCCI and CVP and also results were statistically significant. Minutiello and colleagues (1993)[14], compared the CVP and caval index and demonstrated negative correlation of IVCCI with CVP.

In our study, when the CVP values were below 10cmH2O, the corresponding mean IVCCI values are >50%. Whereas, when the CVP was more than 10cmH2O, the mean IVCCI values were < 50%. The literature shows that IVCCI of more than 50% is suggestive of volume responsiveness and less than 50% suggestive of lack of response to volume loading. These results are in conformity with various studies done by Nagdev AD *et al.*[9], Corl K *et al.*[15] and Akilli B *et al.*[16] which demonstrated that inferior vena cava diameter is not affected by compensatory vasoconstriction, in response to hypovolemia.

Kasuba *et al.*[12] in 1994, in their study including 28 chronic hemodialysis patient, observed gradual reduction in expiratory diameter of inferior vena cava during dialysis, compatible with the amount of fluid extracted and an increase after blood reinfusion following hemodialysis. They showed that the changes in IVC expiratory diameter are more significant than changes in IVC inspiratory diameter. In a study by Tetsuka and colleagues (1995)[13], IVC diameter, circulating blood volume and body weight were found to be decreased by ultrafiltration in patient undergoing hemodialysis and a correlation was found between end-expiratory diameter of IVC and circulating blood volume.

Lyon, *et al.* (2005)[7], have found about 5mm decrease in inspiratory and expiratory diameter of IVC following a 450 ml of blood donation by donors in a study on 31 volunteers. The authors demonstrated the relationship between decrease in circulating blood volume and a reduction in inferior vena cava diameter. They reported that assessment of inferior vena cava diameter with USG in patients with intravascular volume depletion due to trauma or other reasons may be a useful tool.

Similarly, in our study too, there was increase in mean expiratory inferior vena cava diameter after PLR by 1.00mm and 3.40mm mean increase after saline infusion. Whereas, the inspiratory inferior vena cava diameter after PLR and after saline infusion increased from the baseline value by 0.3mm and 3.60mm respectively. On the other hand in mechanically ventilated patients, Lorsomradee, *et al.* (2007)[17] studied on 70 patients the correlation between inferior vena cava diameter and CVP during cardiac surgery and found a correlation between CVP and inferior vena cava diameter in patients with CVP of 11mmHg (14.96cmH2O) or less. With a positive end expiratory pressure of 5 and 10cmH2Oduring cardiac surgery, they found an increase in CVP and inferior vena cava diameter. But they could not show any relationship between CVP and inferior vena cava diameter. In most of studies, the eIVCD has been found to be the better parameter for volume status.[12,18,19]But our study demonstrated almost equal significance of both eIVCD and iIVCD (p value = 0.00). This can be attributed to deep inspiration while taking measurements.

Yanagawa Y and colleagues (2007)[20] reported that inadequate expansion in IVCD was a possible indicator of inadequate circulating blood volume even if blood pressure was normal.The correlation between inferior vena cava diameter, caval index and CVP was studied by Nagdev AD and co-workers (2010)[9] in emergency department patients and concluded that bed side ultrasonographic measurement of caval index greater than or equal to 50% is strongly associated with a low CVP 8mmHg (10.88cmH2O). In our study also the 50% IVCCI correlated to a CVP value of 10cmH2O.

Goldflam and co-workers (2011)[21], studied the state of intravascular volume and reported that the percentage of collapse of vessel will be more in volume depleted patients in comparison with intravascular volume overloaded states. According to their results if inferior vena collapsibility index is > 50% the corresponding CVP range is 6-10cmH2Oand if collapsibility index is < 50% then the corresponding CVP range is 11-15 cmH2O. In our study too, the IVCCI of > 50% is associated with CVP value of < 10cmH2Oand vice versa. Correlation between inferior vena cava diameter as measured with USG and CVP in critically ill patients was studied by Wiwatworapan in (2012)[22]. They found it useful for assessment of volume status. According to this study when eIVCD was lower than 10mm, the CVP would be 10cmH2O (sensitivity 77% and specificity 91%) and when eIVCD was 15mm, CVP would be 15cmH2O (sensitivity 90% and specificity 89%). In our study, eIVCD of baseline was 1.74 ± 0.35cm corresponded to a CVP of 8.10 ± 0.49cmH2Oand peak values of eIVCD was 2.11 ± 0.28cm and CVP was 12.65 ± 1.36cmH2O.

In our study, a highly significant correlation was found between inferior vena cava diameter both inspiratory and expiratory and CVP. There was a statistically significant positive correlation between eIVCD and iIVCD. Results of our study show a cut-off value for CVP as 10cmH2O with respect to IVCCI of 50%. There is a negative correlation between inferior vena cava collapsibility index and CVP value and results of correlation were not statistically significant when CVP value < 10cmH2O. After saline infusion, negative correlation between IVCCI and CVP value persisted and became statistically significant when CVP was more than 10cmH2O. Also when CVP value was < 10cmH2O, the inferior vena cava collapsibility index was >50%. After saline infusion when CVP >10cmH2Othere was decrease in collapsibility of inferior vena cava <50%. Thus according to our experience inferior vena cava collapsibility index can be used as a reliable marker of volume status and CVP in spontaneously breathing patients.

Kircher (1990)[23] in his study also demonstrated that the collapsibility of >50% indicated right atrial pressure (RAP) of below10 mmHg (13.6cmH2O), and collapsibility of <50% indicated a right atrial pressure of above 10mmHg (13.6cmH2O). This study has close resemblance with our study, though correlating relatively higher values of CVP with IVCCI of 50%.

CONCLUSION

Therefore from our study we can conclude that, USG guided respiratory variation in IVCD and IVCCI can be used as simple, reliable, immediate, bedside method to assess the intravascular volume status with reference to CVP. The PLR manoeuvre increases inferior vena cava diameters and decreases inferior vena cava collapsibility index. The fluid loading of 30ml/kg body weight also significantly increases inferior vena cava diameters. In our study, both expiratory and inspiratory inferior vena cava diameters were affected equally by all the manoeuvres and hence we conclude the both inspiratory and expiratory inferior vena cava diameters are equally important.

Since our study has limitations that

1. The sample size was small as our institution ICU had only six beds.
2. The patients were in recovery phase, well hydrated and haemodynamically stable.
3. We did not included mechanically ventilated patients.
4. Therefore, further studies involving large sample size and patients arriving in the hospital in hypovolemic states are warranted.

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