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A Clinical Study on Correlation of Ultrasonographic Measurement of Caval Index with Central Venous Pressure

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Abstract

Background: Central Venous Pressure (CVP) has been used for fluid resuscitation and to check intravascular volume status. A rapid bedside sonographic examination can be instrumental in guiding management of trauma and critically ill patients. This study evaluated the Ultrasonographic (USG) measurement of Inferior Vena Cava (IVC) diameter and caval index to identify intravascular volume status and its correlation with CVP. We also investigated the association of caval index of ≥ 50% and CVP ≤ 8 mm Hg. *Aims:* This study was designed to evaluate Ultrasonographic (USG) measurement of Inferior Vena Cava (IVC) diameter and caval index could identify intravascular volume status and its correlation with CVP. Also, investigating the association of caval index of ≥ 50% and CVP ≤ 8 mm Hg. *Materials and Methods:* A hundred patients aged 18 years and above were enrolled in this prospective, observational study. IVC inspiratory and expiratory diameters were measured by USG. The correlation of CVP and caval index was calculated. Participants were stratified by their CVP ≤ 8 mm Hg and > 8 mm Hg. *Results:* In 100 participants of the study, 68 had a CVP ≤ 8 mm Hg with caval index > 50%. The efficacy of caval index predicting the low CVP (CVP ≤ 8) between the Two Groups was statistically significant. The caval index ≥ 50% predicting a CVP ≤ 8 mm Hg had sensitivity, specificity, positive and negative predictive value of 97%, 96%, 99% and 93% respectively. *Conclusions:* Bedside USG measurement of caval index greater than or equal to 50% is strongly associated with a low CVP and caval index could be a useful tool to determine CVP.

Keywords: Central venous pressure; Inferior vena cava; Caval index; Emergency department; Intensive care unit.

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Introduction

Adequate fluid resuscitation is extremely vital in acutely ill patients, as under correction of intravascular volume is associated with increased morbidity and mortality. Appropriate volume resuscitation optimizes the preload, improves Cardiac Output (CO) and tissue perfusion. But overzealous resuscitation can lead to increased morbidity and mortality.[1–5] Studies have shown that only about half of the critically ill patient's exhibit preload responsiveness.[6]

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The methods of determining the adequacy of volume resuscitation have relied on static and dynamic parameters. The static parameters include Central Venous Pressure (CVP), Pulmonary artery wedge pressure, right and left ventricular end-diastolic volume index. However, all of them require invasive access and none of these are accurate in predicting preload responsiveness.[6–8] There has been a paradigm shift in the approach to predicting hypovolemia with the use of USG.

The dynamic parameters are respiratory variation in CVP, diameter of Inferior Vena Cava (IVC), Superior Vena Cava (SVC), Arterial blood pressure waveform, Passive Leg Raising (PLR) and an actual fluid challenge. Dynamic parameters outperform the static ones in predicting hypovolemia and responsiveness to volume resuscitation.

Some studies propose that in fundamentally sick patients, CVP may not correlate with the successful intravascular volume.[9] Moreover, invasive hemodynamic monitoring has not been found to have a great advantage in sick patients.[10] Pulmonary artery catheters and CVP catheters are time-consuming, intrusive and have major adverse effects. The use of sonography has led to better noninvasive evaluation of intravascular volume status. A quick bedside sonographic examination can be instrumental in directing therapeutic administration.

The absolute IVC diameter changes broadly among healthy adults and by itself may not be diagnostic, the maximal IVC diameter has been found to be lower in patients with hypovolemia.[11] A better indicator of intravascular volume is collapsibility of the IVC. The IVC collapsibility index, also known as the caval index, it is calculated by difference between the maximal (expiratory) and minimal (inspiratory) IVC diameters divided by the maximal IVC diameter. The caval index has been used in spontaneously breathing patients to estimate right atrial pressure.[12,13] Measurements taken during normal respiration have been found to be reasonably accurate.[14] Recent guidelines from the American Society of Echocardiography back the use of IVC diameter and collapsibility of IVC in evaluation of volume status.[15]

We conducted this study to determine if noninvasive, bedside ultrasonographic measurement of the inferior vena cava diameter and caval index could identify intravascular volume status among acutely ill patients and also correlation of Caval Index (CI) of ≥ 50% witch ≤ 8 mm Hg.

Materials and Methods

After obtaining approval from the hospital institutional review board the study was conducted on 100 consecutive cases admitted to the hospital during the study period, satisfying the inclusion and exclusion criteria and consenting to participate in the study. Patients presenting to the ER with trauma or admitted to the ICU with sepsis, septic shock were included in the study. Written informed consent was obtained from the patients before ultrasonographic examination and central vein placement. The inclusion criteria were patients older than 18 years, unintubated and spontaneously breathing. The exclusion criteria were II/III trimester pregnancy, presence of peumothorax/ hemothorax, ascites and raised intraabdominal pressures.

Ultrasonographic guided measurements of inferior vena cava during inspiration and expiration were taken while patients were supine. A low-frequency phased array transducer (3.5–5 MHz) was used to evaluate the IVC. There exists considerable variability in the literature regarding the location at which the IVC diameter should be measured. Most studies agree that the measurement should be distal to the junction with the right atrium and within 3 cm of that point,[12–18] Other studies measure the IVC at or near the junction with the hepatic veins.[19–25] Guidelines from the American Society of Echocardiography recommend an assessment of the IVC just proximal to the hepatic veins, which lie approximately 0.5 to 3 cm from the right atrium, (Fig. 1).[15]

Fig. 1: Sagittal view of the inferior vena cava.

To image the IVC, the probe was placed in the subxiphoid 4-chamber position with the probe marker oriented laterally to identify the right ventricle and right atrium. Then, the probe was aimed toward the spine and the convergence of the IVC with the right atrium was visualized. The IVC was then visualized inferiorly, specifically looking for the confluence of the hepatic veins with the IVC. Inspiratory vena cava and expiratory vena cava diameters were measured just proximal to the hepatic veins, which lie approximately 0.5 to 3 cm from the right atrium, (Fig. 2). Measurements were taken during a normal respiratory cycle. M-mode Doppler sonography of the IVC was used to graphically document the absolute size and dynamic changes in the caliber of the vessel during the patient's normal respiratory cycle. The Caval index (CI) was calculated as CI (%) = (IVC expiratory diameter - IVC inspiratory diameter) × 100.

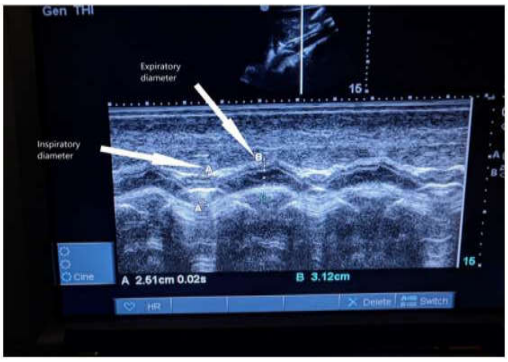

Fig. 2: Sagittal view of the inferior vena cava showing inspiratory and expiratory diameters in M mode.

Simultaneously a right internal jugular catheter was inserted and central venous pressure measurements obtained by digital transduction of the pressure tracing of the distal port the central line after confirmation from a supine chest radiograph that the catheter tip is at the distal aspect of the SVC. Parameters studied included heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, central venous pressure, and inspiratory vena caval diameter. Expiratory vena caval diameter and Caval Index.

Statistical Analysis

Summary statistics were generated for the participants characteristics (age, sex) vital Signs (pulse rate, systolic blood pressure, diastolic blood pressure), and study measurements (central venous pressure, inspiratory vena cava diameter, expiratory vena cava diameter, inferior vena cava and Caval Index percentage.

Sample size calculation

The sample size was calculated taking into consideration the number of admissions in ICU being 6800/year and the number of cases with hypotension 420/year. The incidence being 6.2%, sample size of 89.4 patients was calculated by setting a confidence level at 95%. In order to compensate for loss of data a sample size of 100 used for the study. Data analysis was done with the help of computer using Epidemiological Information Package (EPI 2010) developed by Centre for Disease Control, Atlanta. Using this software range, frequencies, percentages, means and standard deviations, Chi-square and '*p*' values were calculated. Kruskal Wallis and Chi-square test were used to test the significance of difference between quantitative variables, Fisher's test was used for qualitative variables. A '*p*' value less than 0.05 is taken to denote significant relationship. Sensitivity, specificity, accuracy, positive predictive value and negative predictive values were calculated.

Results

A hundred patients were enrolled in this study. The mean age of the patients was 45.52 ± 14.42 years. There were 58 males and 42 females in the final analysis, shows in (Table 1). The number of patients having MAP ≤ 70 mm Hg CVP ≤ 8 cm H_2O and Caval Index ≥ 50 is shown in (Table 2).

Table 1: Demographic parameters (mean ± standard deviation)

Parameter	Mean ± SD
Age (years)	45.52 ± 14.42
Weight (kgs)	60.97 ± 12.46
Sex	Males 58
	Females 42

Table 2: Hemodynamic parameters in patients

Hemodynamic parameter	Number of patients
MAP ≤ 70 mm Hg	54
CVP ≤ 8 cm H_2O	72
Caval Index ≥ 50	72

Participants in the study were stratified by their central venous pressure measurement ≤ 8 mm Hg and > 8 mm Hg. The mean heart rate in the CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group was 113.4 ± 7.9 per minute and 97.6 ± 5.8 per minute. On comparing between the groups *p* value was < 0.001 which was statistically significant. The Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP) and the Mean Arterial Pressure (MAP) was significantly lower in the patients with CVP of ≤ 8 mm Hg group compared to the patients with CVP > 8 mm Hg group. The mean SBP in the CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group at was 86.1 ± 6.0 mm Hg and 108.6 ± 7 mm Hg. On comparing between the groups p value was < 0.001 which was statistically significant. The mean DBP in the CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group was 62.0 ± 3.3 mm Hg and 69.8 ± 4.5 mm Hg. On comparing between the groups p value was < 0.001 which was statistically significant. The mean MAP in the CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group was 69.8 ± 3.6 mm Hg and 80.3 ± 5.6 mm Hg. On comparing between the groups p value was < 0.001 which was statistically significant, shows in (Table 3).

The mean inspiratory vena caval diameter between CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group was found to be 0.54 cm and 1.24 cm and was statistically significant. The mean expiratory venacaval diameter between CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group at was found to be 1.78 cm and 2.23 cm and was statistically significant. The mean caval index between CVP ≤ 8 mm Hg group and CVP > 8 mm Hg group was found to be 70.3% and 44.3 % and was statistically significant (Fig. 3). There is a positive correlation between caval index and a hypovolemic state (patients with CVP ≤ 8 mm Hg), (Table 3).

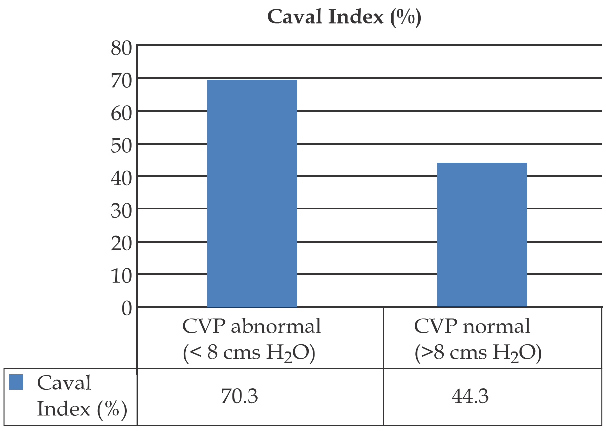

Fig 3: Graph showing correlation of Caval index with central venous pressure (CVP).

Table 3: Hemodynamic variables stratified by their central venous pressure (CVP) ≤ 8 mm Hg and > 8 mm Hg at 0 min

Variable	CVP abnormal (≤ 8 mm Hg) Mean ± SD	CVP normal (>8 mm Hg) Mean ± SD	'p value'
Heart rate (beats/minute)	113.4 ± 7.9	97.6 ± 5.8	< 0.001
Systolic BP (mm/Hg)	86.1 ± 6.0	108.6 ± 7.1	< 0.001
Diastolic BP (mm/Hg)	62.0 ± 3.3	69.8 ± 4.5	< 0.001
MAP (mm/Hg)	69.8 ± 3.6	80.3 ± 5.6	< 0.001
Inspiratory IVC dia (cm)	0.54 ± 0.2	1.24 ± 0.23	< 0.001
Expiratory IVC dia (cm)	1.78 ± 0.26	2.23 ± 0.36	< 0.001
Caval Index (%)	70.3 ± 7.7	44.3 ± 2.8	< 0.001

The efficacy of ultrasound guided measurement of caval index in predicting central venous pressure in our study was found to have a sensitivity of 97%, specificity of 96%, accuracy of 97%, positive predictive value of 99% and negative predictive of 93%. We found to have that caval index a higher sensitivity, specificity, accuracy, negative predictive value and positive predictive value when compared to inspiratory and expiratory vena caval diameter, shows in (Table 4).

Table 4: Comparative efficacy of IVC diameter and Caval Index in predicting central venous pressure

	Sensitivity	Specificity	Accuracy	PPV	NPV
Inspiratory IVC diameter	94	82	91	93	85
Expiratory IVC diameter	93	86	91	94	83
Caval Index	97	96	97	99	93

Discussion

The usage of ultrasound in anesthesia and critical care/emergency care has seen a rapid upsurge in recent times. Estimation of hypovolemic by ultrasound has become a routine in many centres because it is rapid, less time consuming, noninvasive and costeffective. Currently there are many parameters to evaluate hypovolemic state by ultrasound method and the most promising being caval index. Caval index has shown to be most sensitive, specific, and has a high positive predictive value, high negative predictive value when compared to inspiratory, expiratory vena caval diameter or CVP when these were used alone. Caval index being a dynamic parameter takes multiple factor into consideration in determining the volume status and the trend of caval index has found to be more reliable indicator of adequate resuscitation than a single value at any point of time. The complexity and complications of CVP can be overcome by simple noninvasive measurement of inferior vena caval diameter and calculating the Caval Index by ultrasonography. This makes ultrasonographic guided fluid resuscitation most appropriate mode of monitoring intravascular volume status in critically ill patients and in emergency situations. The sonographic evaluation of the IVC has been found to the improve the precision of diagnosis in patients with undifferentiated hypotension.[26]

In a recent study, point-of-care sonography assessing cardiac contractility and IVC collapsibility in patients with suspected sepsis it was found to improve the physician certainty of diagnosis and modify more than 50% of treatment plans.[27] Inadequate dilatation of the IVC after a fluid challenge has been found to be more sensitive than blood pressure for identification of hypovolemia in trauma patients.[28] A study in trauma patients has shown bedside caval sonography extremely useful in assessment of fluid status and resuscitation of critically sick patients.[29] In another study, intensely dyspnoeic patients presenting to the emergency department, IVC sonography quickly recognized patients with congestive heart failure and volume overload.[30] Instead of depending on a single estimation of the IVC, it may be more valuable to take after changes in vessel diameter and collapsibility over time, in relation to an intervention. Studies have shown a decrease in the IVC diameter and increased collapsibility after blood loss and fluid removal during hemodialysis.[31] In hypotensive patients, volume resuscitation was associated with increments within the IVC diameter and lower inspiratory collapsibility.[32]

In our study, we found to have that caval index a higher sensitivity, specificity, accuracy, negative predictive value and positive predictive value (Table 4) when compared to inspiratory and expiratory vena caval diameter. We also found that ultrasound guided measurement of Caval Index could predict the low intravascular volume status in 96% of the cases in the study and their difference with the central venous pressure between the Two Groups were statistically significant ($p < 0.01$). It implies that noninvasive ultrasound guided dynamic measurement of caval index which is obtained by measuring the IVC diameters is reliable to assess the intravascular volume status of the patient and will aid the physician towards goal directed treatment of resuscitation.

Conclusion

We conclude that noninvasive, bedside ultrasonographic measurement of Caval Index is a quick, safe, and reliable method to identify patients with low intravascular volume.

Key Messages

Currently there are many parameters to evaluate hypovolemic state; the ultrasound method is most promising. Caval index being a dynamic parameter has found to be more reliable indicator of adequate resuscitation than a single value at any point of time. Ultrasound guided measurement of caval index could predict the low intra-vascular volume status and thus a low central venous pressure. This technique is noninvasive, easy to measure, inexpensive, fast, and reproducible and also guides the treatment plan.

Abbreviation

MAP = Mean Arterial Pressure

CVP = Central Venous Pressure

IVC = Inferior Vena cava

Caval Index = Maximal (expiratory) - Minimal (inspiratory) IVC diameters/maximal (expiratory) IVC diameter

References

1. Murphy CV, Schramm GE, Doherty JA, et al. The importance of fluid management in acute lung injury secondary to septic shock. Chest. 2009 Jul;136(1):102–109.
2. Boyd JH, Forbes J, Nakada TA, et al. Fluid resuscitation in septic shock: A positive fluid balance and elevated central venous pressure are associated with increased mortality. Crit Care Med 2011;39(2):259–65.
3. Alsous F, Khamiees M, DeGirolamo A, et al. Negative fluid balance predicts survival in patients with septic shock: A retrospective pilot study. Chest 2000;117(6): 1749–754.
4. Vincent JL, Sakr Y, Sprung CL, et al. Sepsis in European intensive care units: Results of the

SOAP study. Crit Care Med. 2006 Feb;34(2):344–53.

5. Reichley RM, Gajic O, Afessa B, et al. National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network. Comparison of two fluid-management strategies in acute lung injury. N Engl J Med 2006;(354):2564–575.
6. Marik PE, Cavallazzi R, Vasu T, et al. Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature. Crit Care Med 2009;37(9):2642–647.
7. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? Chest 2008;134(1):172–78.
8. Michard F, Teboul JL. Predicting fluid responsiveness in ICU patients: A critical analysis of the evidence. Chest 2002; 121(6):2000–2008.
9. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness a systematic review of the literature and the tale of seven mares. Chest. 2008 Jul;134(1):172–78.
10. Shah MR, Hasselblad V, Stevenson LW, et al. Impact of the pulmonary artery catheter in critically ill patients: meta-analysis of randomized clinical trials. JAMA. 2005;294(13):1664–1670.
11. Brennan JM, Ronan A, Goonewardena S, et al. Handcarried ultrasound measurement of the inferior vena cava for assessment of intravascular volume status in the outpatient hemodialysis clinic. Clin J Am Soc Nephrol. 2006;1(4):749–753.
12. Jue J, Chung W, Schiller NB. Does inferior vena cava size predict right atrial pressures in patients receiving mechanical ventilation?. J Am Soc Echocardiogr. 1992;5(6):613–619.
13. Yildirimturk O, Tayyareci Y, Erdim R, et al. Assessment of right atrial pressure using echocardiography and correlation with catheterization. J Clin Ultrasound. 2011;39(6):337–343.
14. Brennan JM, Blair JE, Goonewardena S, et al. Reappraisal of the use of inferior vena cava for estimating right atrial pressure. J Am Soc Echocardiogr. 2007;20(7):857–861.
15. Rudski LG, Lai WW, Afilalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr. 2010;23(7):685–788.
16. Feissel M, Michard F, Faller JP, Teboul JL. The respiratory variation in inferior vena cava diameter as a guide to fluid therapy. Intensive Care Med. 2004;30(9):1834–1837.
17. Sefidbakht S, Assadsangabi R, Abbasi HR, Nabavizadeh A. Sonographic measurement of the inferior vena cava as a predictor of shock in trauma patients. Emerg Radiol. 2007;14(3):181–185.
18. Nagdev AD, Merchant RC, Tirado-Gonzalez A, et al. Emergency department bedside ultrasonographic measurement of the caval index for noninvasive determination of low central venous pressure. Ann Emerg Med 2010;55(3):290–95.
19. Marcelino P, Borba A, Fernandes AP, Marum S, Germano N, Lopes MR. Non invasive evaluation of central venous pressure using echocardiography in the intensive care--specific features of patients with right ventricular enlargement and chronic exacerbated pulmonary disease. Rev Port Pneumol. 2006;12(6):637–658.
20. Barbier C, Loubières Y, Schmit C, et al. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid responsiveness in ventilated septic patients. Intensive Care Med. 2004;30(9):1740–1746.
21. Sakurai T, Ando Y, Masunaga Y, et al. Diameter of the inferior vena cava as an index of dry weight in patients undergoing CAPD. Perit Dial Int 1996;16:183–85.
22. Akilli B, Bayir A, Kara F, Ak A, Cander B. Inferior vena cava diameter as a marker of early hemorrhagic shock: a comparative study. Ulus Travma Acil Cerrahi Derg. 2010;16(2):113–118.
23. Mintz GS, Kotler MN, Parry WR, Iskandrian AS, Kane SA. Real-time inferior vena caval ultrasonography: normal and abnormal findings and its use in assessing right-heart function. Circulation. 1981;64(5):1018–1025.
24. Mitaka C, Nagura T, Sakanishi N, Tsunoda Y, Amaha K. Two-dimensional echocardiographic evaluation of inferior vena cava, right ventricle, and left ventricle during positive-pressure ventilation with varying levels of positive end-expiratory pressure. Crit Care Med. 1989;17(3):205–210.
25. Moreno FL, Hagan AD, Holmen JR, Pryor TA, Strickland RD, Castle CH. Evaluation of size and dynamics of the inferior vena cava as an index of right-sided cardiac function. Am J Cardiol. 1984;53(4):579–585.
26. Jones AE, Tayal VS, Sullivan DM, Kline JA. Randomized, controlled trial of immediate versus delayed goal-directed ultrasound to identify the cause of nontraumatic hypotension

in emergency department patients. Crit Care Med. 2004;32(8):1703–1708.

27. Haydar S, Moore ET, Higgins GL III, et al. Effect of bedside ultrasonography on the certainty of physician clinical decision-making for septic patients in the emergency department. Ann Emerg Med 2012 Sep;60(3):346–58.
28. Yanagawa Y, Sakamoto T, Okada Y. Hypovolemic shock evaluated by sonographic measurement of the inferior vena cava during resuscitation in trauma patients. J Trauma. 2007;63(6):1245–1248.
29. Ferrada P, Anand RJ, Whelan J. Qualitative assessment of the inferior vena cava: useful tool for the valuation of fluid status in critically ill patients. Am Surg 2012 Apr;78(4):468–70.
30. Blehar DJ, Dickman E, Gaspari R. Identification of congestive heart failure *via* respiratory variation of inferior vena cava diameter. Am J Emerg Med 2009 Jan;27(1):71–75.
31. Krause I, Birk E, Davidovits M. Inferior vena cava diameter: A useful method for estimation of fluid status in children on hemodialysis. Nephrol Dial Transplant 2001 Jun;16(6):1203–206.
32. Weekes AJ, Tassone HM, Babcock A, et al. Comparison of serial qualitative and quantitative assessments of caval index and left ventricular systolic function during early fluid resuscitation of hypotensive emergency department patients. Acad Emerg Med. 2011;18(9):912–921.