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Ultrasound-guided estimation of internal jugular vein collapsibility index in patients with shock in emergency department

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Abstract:

OBJECTIVE: To correlate ultrasound-guided estimation of Internal Jugular Vein Collapsibility Index (IJV-CI) with inferior vena cava CI (IVC-CI) and invasively monitored central venous pressure (CVP) in patients with shock in the emergency medicine department.

METHODS: A prospective observational study was done in the emergency department (ED). The study was conducted over 15 months (November 2019 to April 2021). It included patients more than 18 years presenting to the ED in shock. The IJV and IVC diameter and cross-sectional area were measured using ultrasound. The corresponding collapsibility indexes were then calculated and correlated with the invasively monitored CVP of the patient. Data were then analyzed using the Statistical Package for the Social Science (SPSS): Version 23 for windows. Pearson's correlation was used between CVP and collapsibility indexes.

RESULTS: The mean (\pm standard deviation) age of the patients was 49.01 (\pm 15.6). There was a 47 (64%) male predominance which outnumbered females 26 (36%). The correlation coefficient was statistically significant between CVP and the collapsibility indices for various IJV and IVC parameters. The highest correlation ($r = -0.541$, $P = 0.005$) was seen between IVC-CI (CI 5) and CVP. This was followed by a correlation seen at a 30° position for IJV CI (cross-sectional area) with CVP ($r = -0.453$, $P = 0.001$). Similarly, the correlation between IJV CI (AP diameter) and CVP, followed ($r = -0.412$, $P = 0.008$) was statistically significant.

CONCLUSION: Both IJV and IVC collapsibility indices correlated significantly with invasively measured CVP. Hence, they present as an effective tool in fluid resuscitation in patients with shock in ED.

Keywords:

Collapsibility index, emergency department, inferior vena cava, internal jugular vein, shock, ultrasound

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Introduction

The management and hemodynamic monitoring of patients in shock in the emergency department (ED) shock poses an uphill task for the emergency physicians. After the initial resuscitation, assessment

of the fluid status of the patients is very important for further management of hypovolemic patients. This not only aids in grading the severity of shock but also in assessing the response to the initial treatment given to these patients.^[1] Conventionally, clinical parameters such as tachycardia and reduced systolic blood pressure have been

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Box-ED**What is already known on the study topic?**

The assessment of the volume status of a patient in shock is very crucial in their management especially in the emergency department (ED). Many methods have been used conventionally, from clinical examination of the patient to invasive methods like CVP monitoring. However, these methods are not only unreliable but time-consuming in the ED. Noninvasive methods like measuring the diameters of the inferior vena cava (IVC) have been studied in the past as an indirect predictor of CVP. Measurement of the ultrasound parameters can be easily done bedside repeatedly and with minimal expertise.

What is the conflict on the issue? Has it importance for readers?

Measurement of the IVC has limitation. It cannot be done in patients who are obese, or those who are post abdominal surgeries and in intubated patients. An alternative vein which is less studied is the internal jugular vein (IJV) which has varying results with regard to its use in fluid resuscitation. Hence, we studied the different parameters of the IJV diameter and cross-sectional area and compared with IVC collapsibility indices by correlating with invasively monitored central venous pressure (CVP).

How is this study structured?

A prospective observational study done in the ED which included 73 patients.

What does this study tell us?

Both IJV and IVC collapsibility indices are effective tools in fluid resuscitation in patients with shock in ED.

used to assess the hemodynamic status of a patient. However, the role of clinical monitoring is limited and unreliable in critically ill patients.^[2] For example, patients who is elderly with chronic hypertension taking beta-blockers or calcium channel blockers may not show early signs of hemodynamic compromise. Central venous pressure (CVP) has been used mainly in the intensive care unit (ICU) as a measure of right atrial pressure (RAP), which is a major determinant and a good indicator of right ventricular filling.^[3] However, it becomes impractical in the ED as it is time-consuming, requires specialized monitoring equipment and a skilled physician who can place a central catheter. Furthermore, there are immediate, early, and late complications associated with this procedure.^[4] The commonly reported complications are puncturing of the pleura, artery, or the structures around the vein. Catheter-related infections are common if it is kept for an extended period of time.^[5]

Thus, noninvasive techniques such as ultrasound-guided measurement of inferior vena cava (IVC) and internal jugular vein (IJV) parameters have been used recently as an alternative. IVC parameters such as diameters and collapsibility indices can be promptly measured

and calculated bedside and have shown fair to excellent correlation with RAP.^[6,7] They have been measured with a high degree of inter-rater reliability. This has allowed ED clinicians to take appropriate decisions regarding aggressive fluid management.^[8,9] However, measurement of IVC diameter is difficult in patients with abdominal incisions post laparotomy and morbidly obese patients.^[10,11] Other factors that can affect these parameters are increased tricuspid pressure, pulmonary artery pressure, or pulmonary valve disease.^[12] The IJV is an alternative vein that is being recently studied as it is an easily accessible vein. The indices such as IJV anterior-posterior (AP) diameter, width, cross-sectional area, and their collapsibility indices have also been studied as predictors of CVP.^[13,14] However, very few studies in the past have correlated both IJV and IVC indices with invasively measured CVP.

In this study, we aimed to correlate the ultrasound-guided measurements of IJV collapsibility index (CI) and inferior vena CI with invasively monitored CVP in patients diagnosed with shock presenting to the ED.

Materials and Methods**Study design and setting**

This prospective observational study was performed at the ED. Ethical approval was provided by the institution review board on November 29, 2019 (IEC/19/1208). Informed written consent was taken from all the patients and/or relatives after explaining the aims and objectives of the study. The study was conducted over a period of 15 months, from November 2019 to April 2021.

Selection of participants

The patients that were included were 18 years and above presenting to the ED in shock. Shock was defined by a systolic blood pressure <90 mmHg with symptoms and signs suggestive of shock. These patients needed to be actively resuscitated with intravenous fluids such as Ringer's lactate or normal saline. A central venous catheter was inserted in the patients included in the study. We excluded patients who were pregnant, those with increased abdominal pressures, those with pericardial effusion, and mechanically ventilated patients. Patients with pulmonary hypertension, severe tricuspid regurgitation, and pulmonary valve disease were also excluded.

Sample size estimation

The sample size was calculated based on the expected correlation coefficient between IVC and IJV collapsibility made after a review of the literature. A minimum coefficient of -0.35 was expected. At a correlation of -0.35 , a two-tailed α of 0.05 and β of 0.2 (80% power

of study), the sample size calculated was 62, using the formula

$$N = [(Z\alpha + Z\beta) / c]^2 + Z, \text{ where}$$

$$(c = 0.5 \times \ln [(Hr) / (1-r)] = 0.365)$$

A sample size of 70 was taken after taking into account attrition.

Interventions

Detailed demographic and clinical data were collected for every patient. The patient flow chart after meeting inclusion criteria is shown in Figure 1. A central venous catheter was inserted in the right IJV and CVP was measured. We used the SonoSite M-Turbo handheld portable ultrasound machine (SonoSite, Bothell, WA, USA) for all measurements of the IVC and IJV using the curvilinear probe (2–5 MHz) and vascular transducer (5–10 MHz), respectively. We measured the IVC maximum and minimum diameter at the supine position just below the xiphisternum, 1 cm right from the midline at the atrial/hepatic vein/IVC junction where the M mode line was placed 1.5 cm from the hepatic vein [Figure 2]. The IJV diameters (maximum and minimum) [Figure 3] and cross-sectional area (maximum and minimum) [Figure 4] were measured in one respiratory cycle at the level of the cricoid cartilage after confirming the vein from the pulsatile artery by manual compression. This was recorded at the supine position and, at the 30° body position.

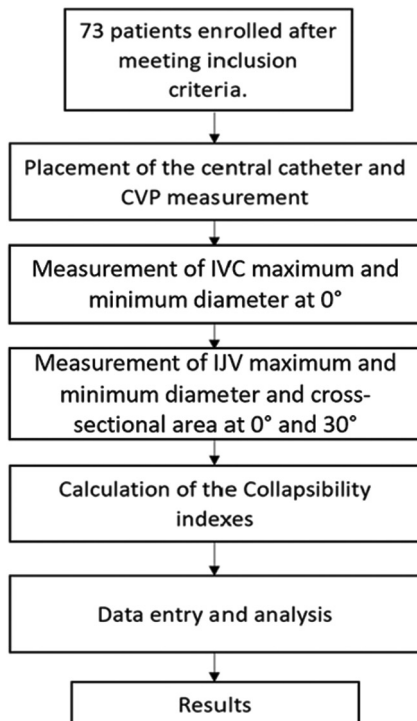


Figure 1: Flow chart following subject enrolment in the emergency department

The IVC CI (IVC-CI) was calculated.

$$\text{Collapsibility index} = \frac{\left(\frac{\text{Maximum IVC diameter} - \text{Minimum IVC diameter}}{\text{Maximum IVC diameter}} \right) \times 100}$$

The collapsibility indices of the IJV parameters (diameter and cross-sectional area) were calculated and recorded as CI 1, 2, 3, 4, and 5.

$$\text{Collapsibility Index} = \frac{\left(\frac{\text{Maximum IJV diameter} / \text{CSA} - \text{Minimum IJV diameter} / \text{CSA}}{\text{Maximum IJV diameter} / \text{CSA}} \right) \times 100}{/ \text{CSA}}$$

CI 1 was CI for IJV cross-sectional area at 0°, CI 2 was CI for IJV diameter at 0°, CI 3 was CI for IJV cross-sectional area at 30°, CI 4 was CI for IJV diameter at 30° and CI 5 was CI for IVC diameter at 0°.

These were then correlated with the measured CVP. The correlated data were then analyzed.

All data were collected by the residents who have been trained by a senior faculty (certified at point of care ultrasound). All the measurements that were taken were supervised.

The identity of the patient was not revealed and confidentiality of all information provided by them was maintained.

Data (or statistical) analysis

Data were then analyzed using the IBM Corp. Released 2015. IBM SPSS Statistics for Windows,

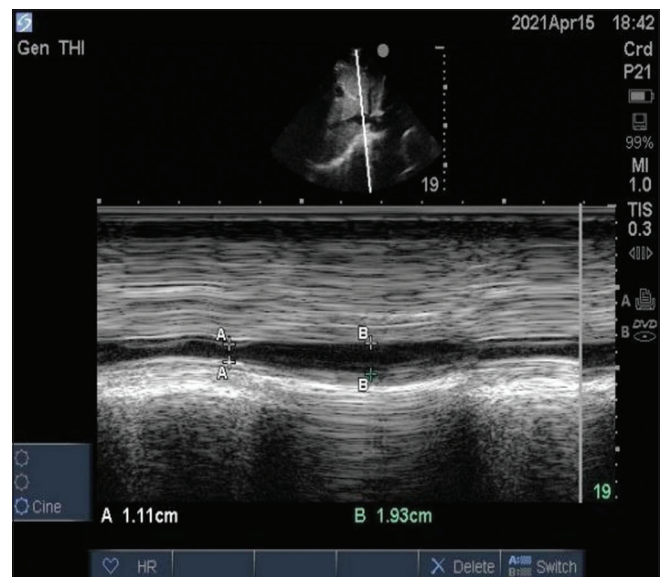


Figure 2: The measurement of the maximum and minimum IVC diameter in M-mode of ultrasound. IVC: Inferior vena cava

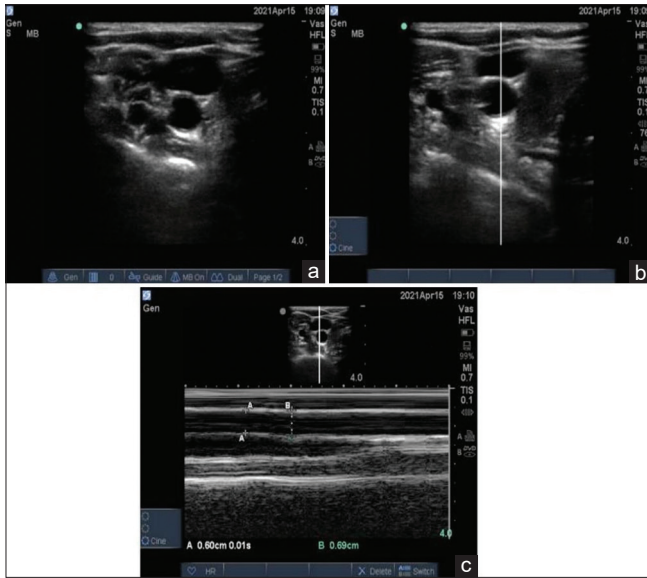


Figure 3: The measurement of the maximum and minimum diameter of IJV in M mode (a Identify IJV in transverse view of the vein, b Place the cursor in M-mode, c measurement of the diameters in M-mode). IJV: Internal jugular vein

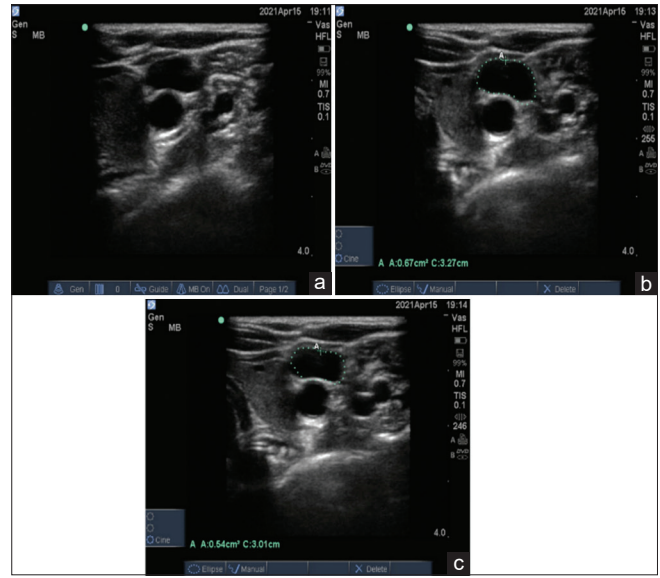


Figure 4: The measurement of the maximum and minimum cross-sectional area of IJV (a - Identify IJV, b-manually draw an ellipse around the vein for both maximum and c- minimum cross-sectional area). IJV: Internal jugular vein

Version 23.0. Armonk, NY: IBM Corp for windows. Continuous variables were presented as mean ± standard deviation (SD). Categorical variables were presented as percentages and absolute numbers. Data were checked for normality before statistical analysis using the Shapiro–Wilk test. Pearson’s correlation was used for correlation between CVP and the collapsibility indexes. $P < 0.05$ (two-tailed) will be considered statistically significant

Results

A total of 73 patients were enrolled belonging to the age group of 21 to 78 years. The mean (\pm SD) age of the patients was 49 (\pm 15.6) years. Males (46; 63%) outnumbered females (27; 37%). Twenty-three (31%) patients required vasopressor support. The baseline characteristics of the patients with shock are summarized in Table 1. Collapsibility indexes were tabulated as CI 1, CI 2, CI 3, CI 4, and CI 5.

The most common diagnosis was pneumonia (30; 41.1%), followed by perforation peritonitis (12; 16.4%) and urinary tract infection (7; 9.6%). Some other provisional diagnoses of patients with shock were pancreatitis (5; 6.8%), acute kidney injury (5; 6.8%), acute febrile illness (4; 5.5%), cellulitis (4; 5.5%), diabetic ketoacidosis (4; 5.5%), upper gastrointestinal bleed (4; 5.5%), and meningitis (3; 4.1%).

Comorbidities were present in 40 patients of whom, type 2 diabetes being the most common (16; 21.9%). This was followed by hypertension (9; 12.3%), chronic obstructive pulmonary disease (7; 0.09%), chronic kidney disease (7; 0.06%), chronic liver disease (4; 0.05%), and coronary artery disease (3; 0.04%).

Table 1: Baseline characteristics of the predictors of shock

Characteristics (mean±SD)	Values
Age (years)	49.01±15.6
Men (%)	46 (67)
Vasopressor support (%)	23 (31)
Heart rate (beats/min)	121.54±13.26
SBP/DBP (mmHg)	72.64±9.36/45.69±8.53
CVP (mmHg)	7.39±1.52
CI 1 (%)	26.80±6.10
CI 2 (%)	18.42±7.03
CI 3 (%)	42.16±8.66
CI 4 (%)	24.40±5.48
CI 5 (%)	55.97±7.08

CI 1: Collapsibility index for IJV cross-sectional area at 0°, CI 2: Collapsibility index for IJV diameter at 0°, CI 3: Collapsibility index for IJV cross-sectional area at 30°, CI 4: Collapsibility index for IJV diameter at 30°, CI 5: Collapsibility index for IVC diameter at 0°. IJV: Internal jugular vein, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, SD: Standard deviation, CVP: Central venous pressure, CI: Collapsibility index, IVC: Inferior vena cava

The collapsibility indices (CI) were correlated with CVP using Pearson’s correlation coefficient. The correlation coefficient was statistically significant between CVP and the collapsibility indices for various IJV and IVC parameters shown in Table 2.

The diameters and cross-sectional area of IJV and IVC were also correlated with invasively monitored CVP [Table 3]. The correlation was highest with the minimum diameter of IVC ($r = 0.521$, $P = 0.006$). This was followed by minimum cross-sectional area of IJV ($r = 0.431$, $P = 0.008$) at 30°. At supine position, the minimum cross-sectional area of IJV had a higher correlation with CVP ($r = 0.381$, $P = 0.007$). All were statistically significant.

Table 2: Correlation between central venous pressure and collapsibility indices

CVP	CI 1	CI 2	CI 3	CI 4	CI 5
Pearson's correlation	-0.374	-0.389	-0.453	-0.412	-0.541
P	0.011	0.015	0.001	0.008	0.005

CI 1: Collapsibility index for IJV cross-sectional area at 0°, CI 2: Collapsibility index for IJV diameter at 0°, CI 3: Collapsibility index for IJV cross-sectional area at 30°, CI 4: Collapsibility index for IJV diameter at 30°, CI 5: Collapsibility index for IVC diameter at 0°. CVP: Central venous pressure, CI: Collapsibility index, IJV: Internal jugular vein, IVC: Inferior vena cava

Table 3: Correlation between central venous pressure and venous parameter (diameter and cross-sectional area) of internal jugular vein and inferior vena cava

	Pearson correlation with CVP	P
IVC maximum diameter	0.096	0.421
IVC minimum diameter	0.521	0.006
IJV - CSA maximum (30°)	0.398	0.026
IJV - CSA minimum (30°)	0.431	0.008
IJV maximum diameter (30°)	0.280	0.128
IJV minimum diameter (30°)	0.403	0.039
IJV - CSA maximum (supine)	0.216	0.054
IJV - CSA minimum (supine)	0.381	0.007
IJV maximum diameter (supine)	0.190	0.107
IJV minimum diameter (supine)	0.391	0.013

IJV: Internal jugular vein, IVC: Inferior vena cava, CVP: Central venous pressure, CSA: Cross-sectional area

Discussion

This was a prospective observational study that was carried out at the ED in India. A total of 73 patients fulfilled the inclusion criteria and were finally enrolled in the study. The mean (\pm SD) age of the patients with shock presenting to the ED was 49.01 (\pm 15.6). There was a 47 (64%) male predominance which outnumbered females 26 (36%) [Table 1]. The initial vital signs in our study showed that the study group was tachycardic, which was attributed to the patient being in shock. A study done also done in India on patients who came to the ED with shock had a mean age of 51.7 (\pm 18.88) and a male predominance of 60%. Their initial vitals also showed tachycardia (106.98 beats/min), a systolic BP of 78.5 mmHg and diastolic of 35.8 mmHg. This was comparable to our study.^[14] The mean value for CVP in our study was 7.4 mmHg. The most common diagnosis was pneumonia (30; 41.1%), followed by perforation peritonitis (12; 16.4%) and urinary tract infection (7; 9.6%). A study which profiled patients coming to the ED saw that out 2782 ED visits (2.1%) who had critical care outcomes; pneumonia was the most common diagnoses similar to ours. In addition, 22,010 ED visits (16.2%) had hospitalization outcome; of which abdominal pain being one of the most common complaints.^[15]

The CI calculated from the IVC and IJV parameters was recorded as CI 1 (IJV-CSA0°), CI 2 (IJV-diam0°), CI 3 (IJV-CSA30°), CI 4 (IJV-diam30°), and CI 5 (IVC-CI).

Similar studies have been done in the past that correlated IJV and IVC parameters with CVP. Jassim *et al.* were

one of the few studies that correlated the collapsibility indices of IJV and IVC parameters with CVP at the supine and 30° position for both cross-sectional area and diameter.^[16] The mean (\pm SD) IVC CI (AP diameter), CI 5, at the supine position for CVP less than 10 mmHg was 37.10 (\pm 19.86)% which was lower than the mean CI 5 in our study (55.97 \pm 7.08). At the supine position, the mean (\pm SD) IJV CI for cross-sectional area (CI 3) and diameter (CI 4) for CVP less than 10 mmHg were 40.78 (\pm 20.75) and 26.97 (\pm 16.45), respectively, which was comparable to our study. At the 30° body position, the mean (\pm SD) IJV CI for cross-sectional area (CI 1) and diameter (CI 2) were 26.4 \pm 16.45 and 20.00 \pm 16.58, respectively, for CVP less than 10 mmHg. This was also comparable to our study as well.

The correlation of IJV-CI with CVP seen in our study at the supine position was similar for both cross-sectional area ($r = -0.374$ $P = 0.011$) and diameter ($r = -0.389$ $P = 0.015$) are shown in Table 2. It was lower than that seen at the 30° body position. Uthoff *et al.* (2012) also conducted a study with 81 patients in random ICU patients. They found a spearman correlation coefficient between CVP and IJV-CI to be $P = -0.408$, which was a moderate correlation comparable to our study.

At 30° position, the correlation coefficient of IJV-CI with CVP were $r = -0.453$ ($P = 0.001$) and $r = -0.412$ ($P = 0.008$) for cross-sectional area and diameter, respectively [Table 2]. This was a moderate correlation similar to the study done by Jassim *et al.*, where the correlation was $r = -0.583$ ($P = 0.0001$) and $r = -0.559$ ($P = 0.0001$), respectively, for both the above parameters.

The correlation coefficient for the (IVC-CI or CI 5) with CVP was $r = -0.541$ ($P = 0.005$) [Table 2], which was statistically significant.^[16]

A systematic review was conducted by Ciozda *et al.*, where 21 studies were found that compared IVC-CI and CVP. Most of the studies showed moderate correlations between IVC CI and CVP which was in concordance with our study. There was heterogeneity across the studies evaluated by them in the timing of IVC size measurement concerning the respiratory cycle but still found a moderately strong correlation between the IVC diameter and CVP similar to ours.^[17] Alavi-Moghaddam *et al.* conducted a meta-analysis and meta-regression by searching 34 studies that included 2843 patients. They found that IVC-CI correlated moderately with CVP ($r = 0.54$). This was also comparable to our study. Their correlation of inspiratory IVC diameter and expiratory IVC diameter with CVP to be $r = 0.60$ ($P = 0.6$) and $r = 0.44$ ($P = 0.14$), respectively, but were not statistically significant.^[18] Our study, however, showed a correlation between minimum IVC AP diameter and CVP that was higher than maximum diameter and

was statistically significant ($r = 0.521, P = 0.006$), as shown in Table 3.

At 30° , the correlation observed with the minimum cross-sectional area of IJV ($r = 0.431, P = 0.008$) was higher than the maximum cross-sectional area and was statistically significant ($r = 0.398, P = 0.026$), as shown in Table 3. Donahue *et al.* also correlated that the IJV diameters at 35° body position. A correlation of $r = 0.67$ and $r = 0.41$ was observed between end-expiration and end-inspiratory cross-sectional area, respectively.^[19] Similarly, the correlation for IJV diameter was higher and statistically significant with the minimum diameter of IJV ($r = 0.403, P = 0.039$) than maximum diameter ($r = 0.280, P = 0.128$) [Table 3]. Donahue found a correlation of $r = 0.63$ and $r = 0.44$ for end-expiratory and end-inspiratory diameter.^[19] Higher correlation were seen at end-expiratory, which is not comparable to our study.

At the supine position, the correlation was higher and statistically significant with the minimum cross-sectional area of IJV ($r = 0.381, P = 0.007$), as shown in Table 3. Avcil *et al.* found a correlation of 0.495 ($P < 0.001$) between the CVP and IJV cross-sectional area.^[13] They did not specify whether it was taken end-expiratory or end-inspiratory. The correlation found by Donahue *et al.* was the same for end-expiratory ($r = 0.69$) and end-inspiratory ($r = 0.69$) with CVP.^[19] Similarly, the correlation was higher and statistically significant with the minimum diameter of IJV ($r = 0.391, P = 0.013$), as shown in Table 3. The IJV max and IJV min diameter correlated moderately with invasive CVP ($r = 0.53, P < 0.001$ and $0.54, P < 0.001$, respectively) by Avcil *et al.* (2015).^[13] In the study by Donahue *et al.*, the correlation was $r = 0.81$ and $r = 0.75$ for end-expiratory and end-inspiratory, respectively.

Limitation(s)

Our study was a single-center study done with a small sample size. This was also done during the peak COVID pandemic which affected the patient population that we received in our ED. We included hypotensive patients as the indications for placing a central venous catheter in a euvolemic patient were limited. Thus, this study lacked a control group needed to measure the area under the curve, specificity, sensitivity, positive predictive value, and negative predictive value.

Conclusions

Point-of-care ultrasound measurement of the venous parameters of both IVC and IJV provides a convenient noninvasive tool for the assessment of intravascular volume in patients with shock presenting to the ED (ED). IJV parameters measured at the 30° body position have proven to be a better indirect predictor of CVP.

STROBE guidelines were used while drafting the document.

Author contributions (CRediT)

Dr HC – contributed to conceptualization, data curation, formal analysis, investigation, methodology, resources, software, validation, writing original draft and writing review/editing

Dr NK – contributed to conceptualization, formal analysis, investigation, methodology, supervision, validation, writing original draft, and writing review/editing

Dr BB – contributed formal analysis, investigation, methodology, supervision resources, validation, writing original draft, and writing review/editing

Dr UC – contributed formal analysis, investigation, methodology, resources, validation, writing original draft and writing review/editing

Dr HB – contributed to data curation, formal analysis, investigation, resources, software, validation

Dr RA - contributed to data curation, formal analysis, investigation, resources, software, validation

Dr SG – contributed to data curation, formal analysis, investigation, resources, software, validation

All authors have approved the submitted version and have agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

Conflicts of interest

None declared.

Consent to participate

A written consent was taken from every patient/next of kin in a language they understand (English or Hindi) before the start of the study.

Ethical approval

Ethical approval was provided by the All India Institute of medical sciences (Rishikesh) Institutional Ethics Committee on 29-11-2019 in the letter AIIMS/IEC/19/1208.

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