To evaluate the relation between central venous pressure and inferior vena cava collapsibility in cases of pediatric shock

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ABSTRACT

Background: Invasive hemodynamic monitoring of central venous pressure (CVP) is a useful guide in directing early resuscitative efforts and assists in reducing the morbidity and mortality of the patients with septic shock. Dynamic parameters like ultrasonographic evaluation of the inferior vena cava (IVC) diameters are becoming increasingly popular method to assess the intravascular volume status. **Objectives:** The objective of this study was to evaluate the relation between CVP and IVC collapsibility in cases of fluid refractory shock. **Methods and Materials:** This was a prospective observational study. Pediatric patients between 1 and 14 years with fluid refractory shock were evaluated. Their CVP was recorded and IVC diameter was measured by ultrasonography during inspiration and expiration. This was calculated as IVC collapsibility index (IVC-CI). Data analysis was done with descriptive statistics, coefficient of correlation, and analysis of variance, as appropriate using SPSS for Windows software (SPSS Inc. Version 20). **Results:** A total of 107 patients with shock were included in the study with the mean age of 7.6 years. Septic shock (93%) was the most common cause of shock and the maximum patients (63%) were in cold shock. Most of these patients had acidosis (mean pH 7.22±0.2), high lactate levels (mean 6.3±3.50 mmol/l), and decreased bicarbonate levels (mean 16.98±5.95 mmol/l). When CVP range was ≤8 mmHg, the mean IVCCI value was >40% and when the CVP range was ≥12 mmHg, the mean IVCCI value was around 20%. Inverse relation between CVP and IVCCI was observed ($r=-0.690$, $p<0.01$). **Conclusions:** There was a strong negative correlation between CVP and IVC collapsibility.

Key words: *Central venous pressure, Inferior vena cava collapsibility, Pediatrics, Ultrasonography, Shock*

Circulatory shock is a major cause of intensive care unit (ICU) admission. Sepsis remains a major cause of morbidity and mortality in developing countries like India and septic shock is usually the most severe kind of shock worldwide. Intravascular volume status assessment is an essential component in the diagnosis and management of shock [1,2]. Determining intravascular volume status and fluid responsiveness based on clinical examination are challenging. Clinicians have been using invasive hemodynamic monitoring as adjunct to plan fluid management. Central venous pressure (CVP) is the most commonly used variable and >90% of the intensivists and anesthesiologists use CVP to guide fluid management [3].

Studies indicate that invasive hemodynamic monitoring of CVP is a useful guide in directing early resuscitative efforts and assists in reducing the morbidity and mortality of the patients with severe sepsis/septic shock [4,5]. However, it is observed that vital signs may correlate poorly with invasively measured intravascular volume status, but ultrasonography (USG)-guided assessment of volume status can be helpful for the fluid expansion [3,6,7]. Furthermore, CVP is dependent on various factors such as right ventricular compliance, peripheral venous tone, posture, pulmonary vascular disease, isolated left ventricular failure, and valvular heart disease.

CVP may actually fall with fluid bolus as sympathetic vascular constriction is relieved. Dynamic parameters, such as USG evaluation of the inferior vena cava (IVC) diameters, are becoming increasingly popular method to assess intravascular volume status. For quick assessment of volume status in the emergency department noninvasively, measurement of IVC-collapsibility index (IVCCI) along with its correlation with CVP should be determined [8]. We planned this study to evaluate the relation between CVP and IVC collapsibility in children with fluid refractory shock.

MATERIALS AND METHODS

This prospective observational study was done in Pediatric ICU, Department of Paediatrics of a tertiary care hospital of north India between January 2016 and October 2017. The study was approved by the Institutional Ethics Committee. Informed consent was taken from parents. Patients aged 1 year–14 years in shock (either compensated or hypotensive) despite fluid bolus of up to 40 ml/kg

Table 1: Cold and warm shock distribution in different CVP ranges (mmHg)

Type of Shock	CVP≤7 (%)	CVP≥8–11 (%)	CVP≥12 (%)	Total	Mean±CVP
Cold shock	44 (65)	10 (15)	14 (20)	68	8.20±3.26
Warm shock	27 (69)	4 (10)	8 (21)	39	8.05±2.56
Total	71 (66)	14 (13)	22 (21)	107	

CVP: Central venous pressure

Table 2: Relation between IVC collapsibility and CVP

CVP range (mmHg)	Collapsibility index percentage (%)			Total
	<25	25–50	>50	
CVP≤7	0	39	32	71
CVP 8–11	10	02	02	14
CVP>12	17	05	0	22

IVC: Inferior vena cava, CVP: Central venous pressure

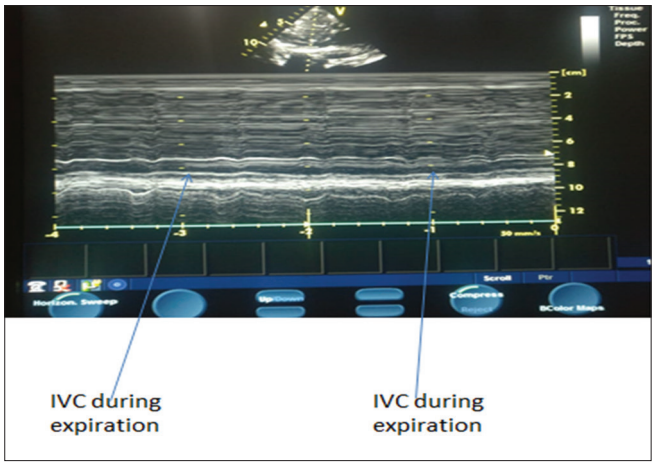

Figure 1: Ultrasonographic view of inferior vena cava (IVC) in longitudinal section at 2 cm distal to the junction of IVC and right atrium (top). M-mode scan of IVC with variation in the internal diameter with inspiration and expiration (bottom)

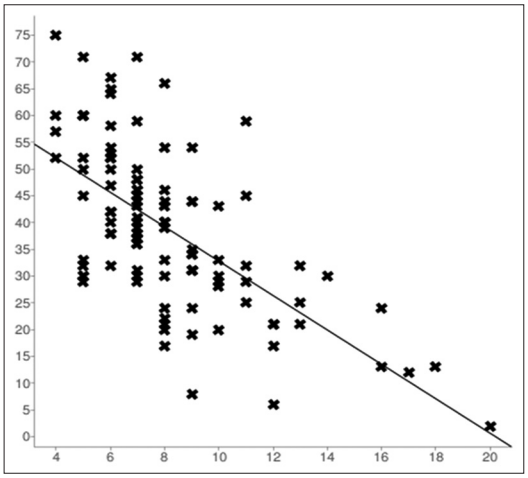

Figure 2: Correlation between central venous pressure and inferior vena cava collapsibility index (IVC-CI) (IVC-CI on y-axis and central venous pressure on x-axis)

over 1 h was included in the study. Patients having structural heart disease/known cardiac disease, myocardial dysfunction, parents not giving consent, patients with clinical signs of elevated abdominal pressure, moderate-to-severe tricuspid regurgitation (TR), CVP inserted for >24 h, patients having poor cardiac window on USG, and patients in whom the supine position was contraindicated were excluded from the study. All consecutive patients satisfying the entry criteria admitted during the study period were included in the study.

Septic shock was defined as (1) hypotension (systolic blood pressure <70 mmHg in infant; <(70+[2 X age] after 1 year of age) or (2) need of vasoactive drug to maintain BP above the 5th centile range (dopamine >5 mcg/kg/min or dobutamine, epinephrine, or norepinephrine at any dose) or (3) signs of hypoperfusion - any three of the following: Decreased pulse volume (weak or absent dorsalis pedis pulse), capillary refill time >3 s, tachycardia, core (rectal/oral) to peripheral (skin-toe) temperature gap >3°C, urine output <1 ml/kg/h, or (4) sepsis and cardiovascular organ dysfunction [9]. Cold shock was characterized clinically by delayed capillary filling time (CFT), i.e., >3 s, cold extremities, and feeble pulses. Warm shock was characterized clinically by flash CFT, i.e., <3 s, warm extremities, and bounding pulses [10].

After taking informed consent, baseline characteristics such as age, sex, length, and clinical volume status were recorded on a pro forma. Vitals were noted. In ventilated patients, the positive end-expiratory pressure (PEEP), peak inspiratory pressure, and FiO2 were recorded after complete sedation and paralysis.

Central venous access was obtained in either internal jugular vein or subclavian vein. Bedside X-ray was done to ensure the tip of the catheter is at the superior vena cava-right atrium (RA) junction, and CVP transducer was attached to obtain CVP waveform. The ultrasound examination of the IVC was done by the pediatric critical care fellow in all the cases, who was blinded to CVP monitoring during the collection of ultrasound data**.** In subxiphoid view, the diameter of the IVC for calculation of the caval index was measured just distal to the junction of hepatic vein with IVC.

To visualize respiratory variation, M-mode was used, with the beam overlying the IVC, just distal to the junction of hepatic vein with IVC (Fig. 1). The inspiratory and expiratory diameters were measured on the M-mode image, at the smallest and largest locations, respectively. The maximum diameter of the IVC during expiration (De) and minimum diameter during inspiration (Di) was recorded. Three back to back measurements of the IVC diameters were made and the average was recorded. This was verified by an in-house Paediatric Cardiologist. IVC-CI was calculated as (De-Di)/De×100% and expressed as percentage.

The decision regarding whether patient needs more fluid or fluid inotrope/vasopressor was based on the CVP values obtained. None of the patients were on any inotropic/vasopressor support at the time of evaluation.

Data analysis was done with descriptive statistics, coefficient of correlation, and analysis of variance, as appropriate. Statistical

Table 3: Age-wise correlation between IVC collapsibility percentage and CVP

Age group (Years)	n (%)	IVC-CI (%)	CVP (mmHg)	Correlation (r)
1–5	34 (32)	33.63 (±15.12)	8.91 (±3.34)	−0.61539
6–10	29 (27)	32.51 (±11.91)	9.24 (±3.44)	−0.634907
10–14	44 (41)	47.09 (13.011)	6.77 (±1.696)	−0.618107

n: Number of patients. IVC: Inferior vena cava, CVP: Central venous pressure, IVC-CI: Inferior vena cava collapsibility index

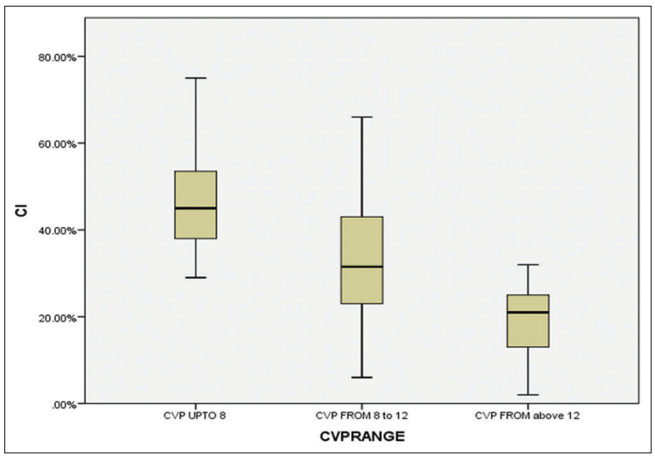

Figure 3: Central venous pressure range versus inferior vena cava collapsibility index

analysis was conducted using SPSS for Windows software (SPSS Inc.). (Version 20) Statistical significance was set at 0.05.

RESULTS

A total of 120 patients were evaluated for the possible inclusion in the study. Out of them, 13 were excluded because five had poor window (secondary to subcutaneous emphysema/shrunken liver); four patients had structural heart diseases such as TR, ventricular septal defect, and tetralogy of Fallot; in two patients, internal jugular/subclavian vein cannulation was failed; one did not give consent and one patient had elevated abdominal pressure. Rest 107 children satisfied the inclusion criteria and included for the final analysis. The mean age of the patients was 7.6±4.15 years. Majority of the patients were female (n=58, 54%) and maximum patients had pneumonia (20 cases). 92 patients (86%) were febrile at presentation. All patients were intubated and ventilated and saturation was maintained in all patients around 97±2.11%.

Maximum patients (68 of 107) were in cold shock. None of the patients had any evidence of myocardial dysfunction. The reason for cold shock was uncorrected hypovolemia rather than myocardial dysfunction. Most of the patients (80.5%) had CFT >3 s. All patients were hypotensive, that is, mean arterial pressure was below the 5th centile for that age and sex even after 40 ml/kg of fluid bolus. Most of the patients had septic shock (93%) and the mean urine output was 1.9±1.4 ml/kg/h. Most of the patients had acidosis (mean pH - 7.22±0.206), high lactate level (mean 6.325±3.498 mmol/l), and decreased bicarbonate level (mean 16.98±5.95 mmol/l). The mean serum sodium and potassium levels were within normal level (140.9±112.58 mmol/l and 3.63±1.04 mmol/l, respectively).

The mean PEEP in mechanically ventilated patients was 5.1±1.1; although PEEP level was reduced to 5 mmHg, 1 min before volume assessment keeping oxygen saturation >94%. Tidal volume was 6 ml/kg in all ventilated patients.

Most of the patients in cold shock (65%) and warm shock (69%) had CVP ≤7. In about 66% of cases, CVP was ≤7, while it was ≥8–11 mmHg in 13% of cases and was above 12 mmHg in the rest 21 cases (Table 1).

In most of the cases, IVC-CI percentage was between 25% and 50%. There were no cases where CVP was >12 mmHg and IVC-CI was >50% (Table 2). Inverse relation between CVP and IVC was observed which was statistically significant (Correlation: −0.690, p <0.01) as shown in Fig. 2.

In all age groups, strong inverse correlation was found between CVP and IVC-CI (Table 3). At CVP of ≤7 mmHg, the mean IVC-CI value was 48.05±11.47 while it was 33.0±13.11% at CVP from 8 to 11 mmHg and 19.82±8.93% at CVP of ≥12 mmHg. The mean CVP was lower (5.95±1.56 mmHg) when IVC-CI was >50% in comparison to CVP of 8.92±3.02 mmHg when IVC-CI was <50%. There was a decreasing trend of mean IVC-CI with progressive increase in CVP values as shown in Fig. 3.

DISCUSSION

In our study, maximum patients were in septic shock (93%) which is comparable to previous studies [1,8,11]. Most of the studies related to this subject were done in adult population with very few studies in pediatric age group [11]. IVC USG has emerged as a promising modality to detect intravascular volume status and volume responsiveness. In our study, among hypovolemic patient (CVP <8 mmHg), all patients had IVC-CI of >25%, and 55% of them had IVC-CI of 25–50%. While in hypervolemic patients (CVP>12), none of the patient had IVCCI of >50% and 77% of patients had IVCCI <25%.

Our study demonstrated decreasing IVC-CI from hypovolemic to hypervolemic state which was similar to previous study by Juhl-Olsen *et al*. which showed IVC-CI values being highest in the hypovolemic patients (45.69±16.15%), followed by the euvolemic patients (31.23±16.77%), and lowest in the hypervolemic patients (17.82±12.036%), and the values were significantly different (p<0.001) [12]. In a study done by Stawicki *et al*., it was found that high IVC collapsibility was associated with low CVP [2]. In our study likewise, none of the patients with CVP <7 showed an IVC-CI of <25%.

We found a negative correlation (r) of −0.690 between CVP and IVC-CI (p<0.01). In all age groups, the correlation between IVCCI and CVP was found as moderately significant (r^2=−0.615,

−0.634, and −0.618 in age Group 1–5 years, 6–10 years, and 10–14 years, respectively). It was observed that the mean CVP value is lower when IVCCI >50% compared to IVCCI <50% (mean CVP values were 5.95±1.56 and 8.92±8.92, respectively).

Several studies have been done to determine the relation between IVC-CI and CVP. Stawicki *et al*. showed that mean CVP values were inversely proportional to the IVC-CI (p=0.023) [2]. In a meta-analysis of 21 studies published in 2016 with exclusively adult populations, sonographic measurement of IVC was compared with CVP. A pooled correlation between IVCI and CVP was 0.66–0.93, thus emphasizing on the usefulness of IVC-CI as a surrogate marker for CVP [13]. Ilyas *et al*. studied 100 adult ICU patients and found a strong negative correlation between CVP and IVC-CI (r=−0.827, n=100, p<0.0005) [14].

The relevance of IVC assessment is more in patients with shock. Several studies were identified in which adult patients with shock were assessed. Stawicki *et al*. found inverse correlation between IVCCI and CVP among 79 adult patients with shock, with each 1 mmHg of CVP corresponding to 3.3% median IVCCI. Low IVCCI (<25%) was consistent with euvolemia/hypervolemia, while IVCCI >75% suggested intravascular volume depletion [15]. Iwamoto *et al*. studied 118 children with cardiovascular disease and found significant correlation between IVCCI and CVP (r^2=060, p<0.01), and IVC-CI of 0.22 best-predicted CVP >10 mmHg, with a sensitivity of 100% and specificity of 93% [16].

There were certain limitations of the present study. First, USG was not done by sinologist; however, to minimize the errors, all the images with measurements were recorded and verified by our in-house cardiologist. Second, the sample included only ventilated population.

CONCLUSION

There was a strong negative correlation between CVP and IVC collapsibility (IVC-CI). However, these values were correlated only at one point of therapy; therefore, further studies are needed to evaluate the relation between CVP and IVC at different time frame until shock treatment goals are achieved.

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