

A Comparison between the Bedside Sonographic Measurements of the Inferior Vena Cava Indices and the Central Venous Pressure While Assessing the Decreased Intravascular Volume in Children

Abstract

Background: Hemodynamic monitoring is an essential part in the treatment of critically ill patients. Establishment of intravascular volume and creation of a normal systemic perfusion are the most important part to reduce the risk of organ failure and mortality. This study aimed to determine the correlation between the inferior vena cava (IVC) sonographic indices and the central venous pressure (CVP) to provide a useful guide for noninvasive intravascular volume status assessment in children. **Materials and Methods:** Target sample of children who were admitted to the pediatric critical care unit and required CVP monitoring were enrolled in this study. The collapsibility index (CI) and IVC/aorta (AO) ratio, from bedside ultrasonography measurement of the IVC, were calculated. **Results:** Of the 70 participants, 22 patients (31.4%) revealed a CVP of 8 mm/Hg or less and 48 patients (68.6%) revealed a CVP >8 mm/Hg. Fifty-six patients (80%) had an IVC-CI of 0.5 or greater and 17 patients (24.3%) had an IVC/AO of 0.8 or less. IVC-CI index is 45.5% sensitive and 91.7% specific with positive predictive value of 71.4 and negative predictive value of 78.6 to predict CVP <8, and the IVC/AO index is 50.8% sensitive and 87.5% specific with a positive predictive value of 64.7 and a negative predictive value of 79.2 to predict CVP <8. **Conclusion:** Based on the present finding, the IVC sonographic indices provide a useful guide for noninvasive intravascular volume status assessment in children.

Keywords: Bedside ultrasound, central venous pressure measurement, inferior vena cava indexes, intravascular volume

Introduction

Hemodynamic monitoring is essential in the treatment of patients in the pediatric Intensive Care Unit (ICU).^[1,2] Establishment of the intravascular volume with fluids and vasoactive drugs and creation of a normal systemic perfusion is one of the most important parts to reduce the risk of organ failure and mortality.^[3,4]

It is necessary to achieve a standard method for the assessment of intravascular volume that correlates with the clinical findings and history^[5-8] because these methods do not reveal sufficient sensitivity and specificity, and the assessment of the patient's volumetric status is influenced by the personal interface of the individual.^[9,10] Considerably, the use of central venous pressure (CVP) through central venous catheter is a standard method that is used in the ICUs. CVP is good approximation of right atrial pressure which in turn is

a major determinant to right ventricular filling, and therefore, good indicator of right ventricular preload; however, this method is invasive and indicates complications such as hemothorax, pneumothorax, emboli, and infection while using it, and it is not possible to use this method in an emergency situation as it requires skilled personnel.^[11,12]

The use of inferior vena cava (IVC) sonographic indices to assess the intravascular volume in a wide range of adult patients has been studied in several researches since 1979 and is associated with the acceptable results. Of present, in the adult emergency medicine and ICU, these indices are widely used as a noninvasive, rapid, and reliable method for assessing the volume status. Studies on IVC index such as IVC diameter, IVC collapsibility (decreased IVC diameter at inspiration time), and IVC to aorta (AO)

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diameter were performed, and each of these indices was compared with the CVP.^[13-18] Considering that studies in this field are very limited in children and that study has not been conducted in accordance with the results of the extensive studies performed in adults, we aimed to compensate by eliminating or minimizing the confounding factors in measuring CVP and IVC sonographic indices, measure these indices in children, and compare them with CVP.

Materials and Methods

This was a prospective observational study.

The study was conducted from May 2016 to March 2017 for 11 months for the hospitalized children in the ICU of Tehran Children's Medical Center.

Inclusion criteria were the children between 1 month and 12 years, admitted in these critical care units, with indwelling central venous catheter for invasive hemodynamic monitoring, Patients under mechanical ventilation receiving maximum positive end-expiratory pressure (PEEP) of 6 cmH₂O, Patients receiving vasoactive agent as a continuous infusion with epinephrine <0.05 µ/kg/min and dopamine <10 µ/kg/min and Central vein catheterization under 24 h.

The patients with abdominal pathology, Limitation in the supine position or access to intended sonographic view were excluded.

The target patients participated in the study based on the defined criteria, and the demographic data including age, gender, primary diagnosis, intubation status, the site of central line insertion, pressure needed to avoid collapsing of alveoli in end-expiratory (PEEP) number in intubated patients, use of sedation and/or vasopressors, and CVP level were registered in the questionnaire. After preparing the patient for bedside ultrasonography (BUS), the two interns of the 2nd year, who were trained by an expert pediatric cardiologist, measured the sonographic indices.

The BUS measurements were obtained with a TOSHIBA-Aplio system using the 5 MHz phased array transducer. The patient was placed in the supine position and all measurements were collected in this position.

First, in the subxiphoid sagittal view, the transducer was placed in the subxiphoid region and the liver was used as the acoustic window, and distal to the junction of the IVC and hepatic vein, M-mode was used to capture a 15s cine loop of the IVC over 5 respiratory cycles. The maximal and minimal anterior–posterior IVC diameters between the two internal walls of the Venus were measured, and the collapsibility index (CI) was calculated according to this formula ($[\text{max IVC} - \text{min IVC}] / \text{max IVC} \times 100\%$) [Figure 1].

Furthermore, in transverse–subcostal view, the transducer was placed in the subxiphoid region, and the liver was

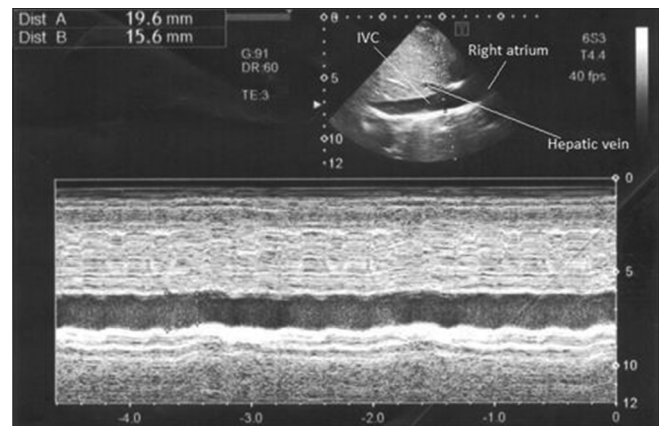


Figure 1: Sagittal view of the inferior vena cava

used as the acoustic window to visualize the AO at the level of regression of the left renal artery from the AO. The maximal anterior–posterior diameter of both IVC and AO were measured to calculate the IVC/AO ratio [Figure 2].

In any step of sonography, images were printed and attached to the questionnaires. To match with the previous literature, dehydration was considered as CVP of 8 mmHg or less, a CI of 50% or greater, and IVC/AO of 0.8 or less. At the end of sonography, the CVP value that was obtained during the sonography examination by the nursing staff was reported. This measurement was obtained in the supine position through digital transduction of the pressure tracing of the distal port of the central line, and the numeric value was recorded after the transducer was rezeroed in the midaxillary line. The study investigators were blinded to CVP measurements. Data were collected in 21 versions of SPSS) IBM, NY, USA) and was statistically analyzed. Descriptive statistics for all qualitative variables was calculated. Chi-square test and Pearson correlation coefficient were used to determine the relationship between CVP and sonographic IVC indices, and $P < 0.05$ was considered as statistically significant.

Results

Over the course of the study, according to the inclusion and exclusion criteria, 70 patients were included (54.3% male; mean age 36.8 ± 40.7 standard deviation months).

Thirty-six patients (45.1%) were intubated with the mean PEEP of 5 cmH₂O

About 47.1% of patients received vasoactive agent and 38.6% were sedated. The right femoral vein was mostly used as the CVC insertion site.

The mean CVP maintained was 10.64 ± 3.85 mm/Hg with a CI of 35.3 ± 16.3 and IVC/AO of 1.09 ± 0.4 .

A total of 22 patients (31.4%) revealed CVP of 8 mm/Hg or less and 48 patients (68.6%) indicated CVP >8 mm/Hg.

A total of 56 patients (80%) revealed IVC-CI of 0.5 or greater and 17 patients (24.3%) indicated IVC/AO of 0.8 or less.

Baseline characteristics of the patients are summarized in Table 1.

Pearson correlation was used to determine the relation between CVP values and the IVC-CI and IVC/AO indices. A strong negative linear correlation was observed between the CVP (10.64 ± 3.85 mm/Hg) and IVC-CI index (35.3 ± 16.3), which was statistically significant ($P < 0.001$ and $r < 0.685$), as presented in Figure 3.

A strong positive linear correlation was observed between the CVP (10.64 ± 3.85 mm/Hg) and IVC/AO (1.09 ± 0.4), which was statistically significant ($P < 0.001$ and $r < 0.423$), as presented in Figure 4.

To assess the relation of CVP and IVC-CI and IVC/AO, IVC-CI variable was categorized in $IVC-CI \geq 0.5$ and $IVC-CI < 0.5$ and IVC/AO variable was categorized in $IVC/AO < 0.8$ and $IVC/AO > 0.8$. Moreover, these cases were compared to CVP < 8 and CVP > 8 groups, which indicated a significant relation ($P < 0.001$).

Table 2 compares the IVC sonographic indices with the CVP measurements.

IVC CI is 45.5% sensitive and 91.7% specific with a positive predictive value of 71.4 and a negative predictive

value of 78.6 to predict CVP < 8 mm/Hg, and IVC/AO index is 50.8% sensitive and 87.5% specific with a positive predictive value of 64.7 and a negative predictive value of 79.2 to predict CVP < 8 . This data is presented in Table 3.



Figure 2: Transverse view of the inferior vena cava

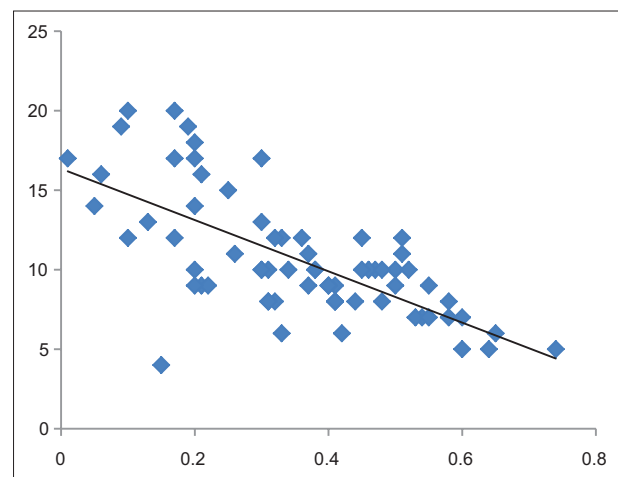


Figure 3: A Strong negative correlation was revealed between central venous pressure and inferior vena cava collapsibility ($r = 0.685$ $n = 70$)

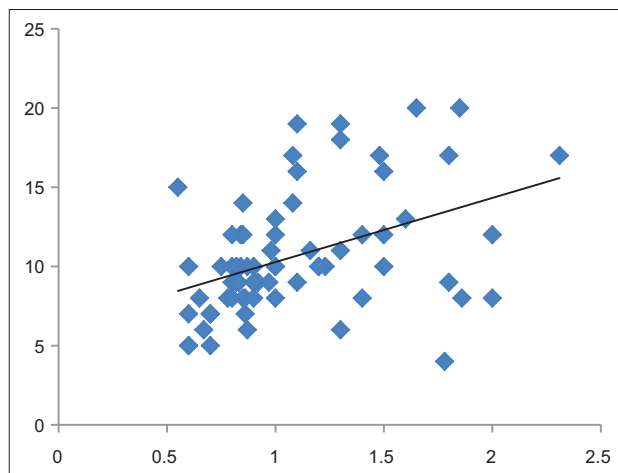


Figure 4: A strong positive correlation was revealed between central venous pressure and inferior vena cava/aorta ($r = 0.423$ $n = 70$)

Table 1: Demographic data of critically ill patients

Parameters	All patient (70)
Age (months), median (interquartile range)	36.8 (1.5-144)
Sex, n (%)	
Male	38 (54.3)
Intubate with PEEP ≤ 6 cmH ₂ O, n (%)	36 (45.1)
CVL site, n (%)	
Right femoral vein	29 (41.4)
Left femoral vein	17 (24.3)
Right subclavian vein	15 (21.4)
Left subclavian vein	2 (2.9)
Right jugular vein	7 (10)
Admission diagnosis, n (%)	
Cardiac	31 (44.3)
Respiratory	18 (25.7)
Infection	9 (12.8)
CNS	12 (17.1)
Vasoactive given, n (%)	
Epinephrine drip < 0.05 μ /kg/min	33 (47.1)
Dopamine drip < 10 μ /kg/min	33 (47.1)
Sedated, n (%)	27 (38.6)
Central vein pressure, n (%)	
CVP ≤ 8	22 (31.4)
CVP > 8	48 (68.6)

CVP: Central venous pressure, CNS: Central nervous system, CVL: Central venous line, PEEP: Positive end-expiratory pressure

Table 2: Inferior vena cava versus central venous pressure measurements

Sonographic Indices	CVP		P
	≤8 mmHg (n=22)	>8 mmHg (n=48)	
Collapsibility index ≤0.5, n (%)	10 (45.4)	4 (8.3)	<0.001
IVC/AO ≥0.8, n (%)	11 (50)	6 (12.5)	<0.001

AO: Aorta, IVC: Inferior vena cava, CVP: Central venous pressure

Table 3: Performance parameters of inferior vena cava measurements as predictor of central venous pressure 8 mmHg or less

Type of indices	Collapsibility index ≥0.5	IVC/AO ≤0.8
Sensitivity	45.5	50
Specificity	91.7	87.5
Positive predictive value	71.4	64.7
Negative predictive value	78.6	79.2

AO: Aorta, IVC: Inferior vena cava

Discussion

Quick evaluation of the intravascular volume in the critically ill pediatric patients is essential since in the case of missing diagnosis of the decrease in intravascular volume, presumably the patient may enter a shock position. Using BUS has several benefits over the standard CVP measurements, and it is possible to calculate the intravascular volume with lesser time and complications compared to accessing the central vein, using it as a guide to start the treatment and evaluate response to the treatment. This study is the second survey on children relating to the evaluation of IVC ultrasonography criteria (IVC collapsibility, AVC/AO) using CVP.

A significant relation has been observed between IVC and CVP in different studies on adults. For example, in one of the latest studies, Ciozda *et al.* (2016) used a systematic method for evaluating the results of 21 last studies and found a considerable relation between IVC diameter and IVC collapsibility by comparing the calculated CVP (C-static = 0.5–0.76 for IVC diameter and 0.66–0.93 for IVC collapsibility). It was concluded that measuring the IVC collapsibility and IVC diameter can be considered as a reliable method for calculating the intravascular volume as a substitute for measuring CVP in adults.^[19]

In addition, Sridhar *et al.* (2014) and Naghipoor *et al.* (2015) reported that the IVC/AO ultrasonography index revealed a significant relation with CVP ($P < 0.001$); therefore, this index is reliable in evaluating the intravascular volume in adults.^[20,21]

In pediatric studies considering the IVC collapsibility indices and ratio of IVC/AO and its comparison with

CVP, Lerrain Ngr *et al.* (2012) studied 51 patients in pediatric ICU (PICU) of Montefiore center, New York. No significant relation was observed between the IVC indices with IVC/AO ≤0.8, IVC-CI ≥0.5, and CVP <8 mm/Hg; therefore, using ultrasonography to evaluate the decrease in the intravascular volume in pediatric patients was reported as an unreliable method.^[22]

The results of our study were in accordance with the results of studies on adults in evaluating these two indices of IVC ultrasonography compared to CVP. In this study, we tried to eliminate or minimize the confounding factors affecting the CVP measurement and IVC ultrasonography parameters. Since these measurements are performed using IVC, which has no valve and elastic properties, especially in children, this elasticity is increased in the chest wall due to smaller body mass; confounding factors will have greater influence in measuring. One of the major difference between our study and the others for pediatric patients was excluding children under mechanical ventilation with PEEP of >6 cmH₂O; therefore, the number of patients under mechanical ventilation from the previous study was reduced from 67% to 45%, and in addition, patients with high physiological PEEP (pressure needed to avoid collapsing of alveoli in end expiratory) were excluded, which can inverse the normal pressure gradient in inspiration and expiration between the thorax and abdomen, and therefore, affect measurements in the vein.^[23,24]

Furthermore, we excluded the postoperative abdominal pathology patients and patients with intra-abdominal pathologies, which can reveal increased intra-abdominal pressure and affect the mentioned gradient. Since the vasoactive drugs can indicate vasoconstriction effects on the vascular wall, and thus influence IVC and CVP, patients receiving vasoactive medication with doses less than sufficient for activating the alpha receptors and starting vasoconstriction, were included in the study.^[25]

Small sample size according to the inclusion criteria was one of our limitations. Sedative drugs in patients under mechanical ventilation indicated another limitation of our study because its effects on the vascular wall during CVP measurement and IVC indices are not predictable according to the receiving dose. We could not exclude or define an inclusion criterion for these patients. In 65.7% of the included patients, CVP was measured using the femoral vein, which can affect the calculations through jugular and subclavian veins.

In this study, the number of included patients with severe dehydration who needed critical treatment was not dominant (22 people or 31.4% had CVP <8) because the patients were admitted in PICU and benefited from partial stability; however, changes in the intravascular volume was sufficient to be tracked by ultrasonography.

As it was reported in the previous studies, patients with CVP <10 have a higher chance of responding to the hydrotherapy challenge due to an increase in the heart output, and therefore, changes in the intravascular volume and IVC ultrasonography indices are more tangible;^[26,27] hence, it seems that repeating this study in the emergency room and on patients who need acute treatment intervention can be considered in the future studies, and presumably, we can compare the changes in CVP and IVC ultrasonography indices before and after treatment.

In addition, using bigger sample with more limitations regarding inclusion of patients under mechanical ventilation and exclusion of effects of PEEP and sedative drugs can minimize the confounding factors in this study.

Conclusion

Based on the present finding, we can find significant correlation between the IVC sonographic index including IVC-CI and IVC/AO with CVP. The authors conclude that the IVC-CI and IVC/AO indices can provide a useful guide for noninvasive intravascular volume status assessment of the pediatric critically ill patients. It seems that IVC sonographic indices and CVP measurements in bigger sample of patients who need acute treatment intervention before and after treatment can be helped to assess the sonography roles in the pediatric critically ill patients in the future studies.

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Conflicts of interest

There are no conflicts of interest.

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