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Ultrasonographic inferior vena cava collapsibility and distensibility indices for detecting the volume status of critically ill pediatric patients

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Abstract

Especially in recent years, the use of point-of-care ultrasound by non-radiologist clinicians has become widespread. Point-of-care ultrasound provides rapid responses to the problems of critically ill patients at the bedside. This technique has many important advantages, including being non-invasive, cheap, repeatable, painless, and radiation-free. Numerous studies have revealed the most important clinical benefits of point-of-care ultrasound use by pediatric intensive care providers. The inferior vena cava is a vessel that is highly sensitive to fluid changes. The inferior vena cava diameter can be measured by a point-of-care ultrasound, and represents a critical parameter in assessing the patient's fluid status. The inferior vena cava collapsibility index (in spontaneously breathing patients) and the inferior vena cava distensibility index (in mechanically ventilated patients) are calculated by determined formulas by using maximum and minimum diameters of the inferior vena cava. The indices are important guides for pediatric intensive care providers for managing their patients' fluid treatment. Although some authors claim it is not a reliable method, the technique is coming to fore in intensive care units day by day, and has an increasing trend among pediatric intensive care specialists. Here, we aim to give detailed information on the ultrasonographic inferior vena cava diameter measurement methods, and calculations of the inferior vena cava collapsibility index and inferior vena cava distensibility index, and emphasize the importance of a non-invasive, bedside, and objective method of detecting the volume status of critically ill patients for pediatric intensive care specialists according to the published literature.

Introduction

A point-of-care ultrasound (POCUS) is a type of bedside ultrasonographic assessment that is applied by the clinician in charge⁽¹⁾. It provides rapid and real-time answers about patients' clinical problems. The use of POCUS by clinicians has become common in recent years, especially in emergency and intensive care departments⁽²⁾. Around the world, the number of POCUS training courses intended for pediatric intensive care and emergency care specialists is increasing, and the newest generation of pediatricians has an interest in POCUS application. In fact, in recent years, POCUS has become part of the process of physically

examining critically ill children in pediatric intensive care units (PICUs)⁽³⁾. Through POCUS results, clinicians are able to manage treatment options without requiring external consultation. The technique has many important advantages, for example it is easy to use, and can be repeated. It is also noninvasive, inexpensive, painless, and radiation-free⁽¹⁾. Most pediatric intensive care societies, including the European Society of Pediatric and Neonatal Intensive Care (ESPNIC), provide advanced training courses, and encourage a new generation of pediatric intensive care specialists to use POCUS. The ESPNIC has also published international evidence-based guidelines on POCUS for neonates and children who are seriously ill. The organization has

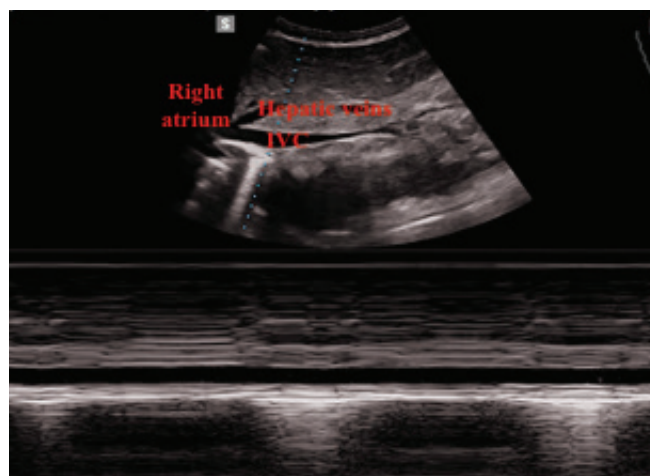


Fig. 1. M-Mode images of the inferior vena cava draining into the right atrium

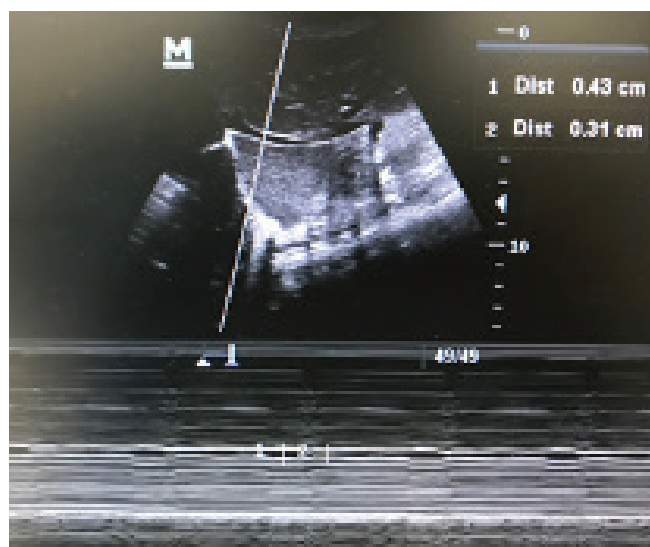


Fig. 2. Maximum and minimum diameter measurements of the inferior vena cava on breathing circulation IVC

recommended using POCUS in intensive care units based on strong evidence⁽⁴⁾.

There are different types of POCUS applications that are commonly used. These include critical-care echocardiography (to evaluate myocardial contractility and cardiac index measurements or detect pericardial tamponade), lung ultrasounds (to evaluate pneumothorax, pleural effusion and pneumonia, and ultrasound-guided thoracentesis), vascular ultrasounds (to insert a central venous catheter, peripheral venous catheter, or invasive arterial catheter), optic nerve sheath diameter measurements (for the clinical follow-up of increased intracranial pressure), fast intra-abdominal assessments (to detect perihepatic or perisplenic hemorrhage), inferior vena cava (IVC) maximum and minimum diameter measurements (to evaluate the volume status of patients), confirmation of endotracheal tube and nasogastric tube placement, and management of cardiopulmonary resuscitation⁽⁵⁻¹²⁾.

Critically ill patients in PICUs frequently have critical and urgent problems. This patient group requires closer follow-up and needs quick assessments due to their hemodynamically unstable situation⁽¹³⁾. Detecting volume status and planning appropriate fluid therapy as well as inotropic, vasopressor, and inodilator treatments is vitally important, especially for patients in shock⁽¹³⁾. Appropriate fluid therapy is an important step in reducing the morbidity associated with multiple organ failure and mortality⁽¹⁴⁾. Skin turgor, heart rate, mean arterial pressure, urine output, and central venous pressure (CVP) are variables used to assess the patient's intravenous fluid status⁽¹⁵⁾. There are increasingly more studies, however, which suggest that the results obtained from these variables differ depending on personal assessments. This has raised the need for new methods to find more objective results about the volume status of critically ill children⁽¹⁶⁾.

The IVC is a vessel that is highly sensitive to fluid changes. It is collapsible, and varies in size depending on respiratory changes under intrathoracic pressure. During spontaneous breathing, the vessel closes on inspiration and opens on expiration. The IVC diameter can be measured by a POCUS quickly, non-invasively, and easily, and it is a critical parameter in assessing the patient's fluid status⁽¹⁷⁾. Several studies on adults have demonstrated that changes in the IVC diameter can be used to determine the patient's fluid status, but data obtained from children are still limited^(18,19).

In this article, we aim to give detailed information about IVC diameter measurement methods as well as calculations of the IVC collapsibility index (in spontaneously breathing patients) and the IVC distensibility index (in mechanically ventilated patients). We want to review the role of these measurements in the PICU setting, and emphasize the importance of a non-invasive, bedside, and objective method of detecting the volume status of critically ill patients for pediatric intensive care specialists based on the published literature.

Ultrasonography technique for IVC measurements

IVC collapsibility (in spontaneously breathing patients) and IVC distensibility (in mechanically ventilated patients) indices are measured by bedside ultrasonography. Measurements are performed while the patient is in the supine position. Generally, a 2–5-MHz convex probe is used for the assessment. A sterile ultrasound gel is placed over the transducer at room temperature to obtain high-quality images. IVC images are acquired in the sagittal section. To obtain a sagittal image, the probe is placed in the subxiphoid area and the liver is used as an acoustic window. Images of the IVC draining into the right atrium are obtained while the probe is in the subxiphoid area (Fig. 1). The minimum IVC diameter on inspiration and the maximum IVC diameter on expiration are recorded using M-mode just beyond the point where the hepatic veins drain into the IVC (Fig. 2). The maximum IVC diameter on inspiration and the minimum IVC diameter on expiration are measured using the same ultrasonographic method in intubated children for the vena cava distensibility index⁽¹⁹⁾.

The IVC collapsibility index is calculated by the following formula: IVC collapsibility index = [maximum diameter on expiration – (minimum diameter on inspiration/ maximum diameter on expiration)]⁽²⁰⁾. In mechanically ventilated patients, the IVC distensibility index is calculated using the formula: IVC distensibility index = [(maximum diameter on inspiration – minimum diameter on expiration)/ minimum diameter on expiration]⁽²¹⁾.

Pediatric literature on IVC collapsibility index

Although there is a wide range of literature on adult patients, studies on pediatric patients are still limited, though an increasing number of studies look promising⁽¹⁹⁾. Again, pediatric data about these reference values are limited⁽²²⁾. Because of the lack of literature for pediatric age groups, the reference values defined for the IVC collapsibility index and the maximum and minimum diameters of IVC are derived from the adult population. In adults, an IVC collapsibility index of greater than 50% is associated with reduced right atrial pressure and severe dehydration, and indicates that the patient needs fluid therapy⁽²³⁾. Mannarino *et al.*⁽²⁴⁾ evaluated 516 healthy Italian children and gave reliable reference values for IVC diameters. In that study, the authors noticed that the reference value of the IVC collapsibility index was 30% for children older than one year, and 36% for children younger than one year. Another pediatric study aimed to obtain reference values for the IVCs in healthy children by evaluating a total of 475 Indian children from ages one to 12. The authors gave reference values of the IVCs for the age groups and noticed a positive correlation between the maximum and minimum IVC diameters as well as somatic parameters like age, weight, height, and body surface area⁽²⁵⁾. Kathuria *et al.*⁽²⁶⁾ evaluated 63 children, aged zero to 22 months, without dehydration, in a pediatric emergency department. Their hypothesis was based on finding normative data for ultrasonographic IVC measurements. The authors detected a correlation between age and the minimum and maximum diameters of the IVC. A study by Kutty *et al.*⁽²⁷⁾ evaluated 120 healthy American children with a mean age of 8.3 years. They demonstrated a mean maximum IVC diameter of 12.1 ± 3.8 mm and a mean minimum IVC diameter of 8.9 ± 3.8 mm during spontaneous breathing. The IVC collapsibility index was 30 percent.

CVP is a standard of care for evaluating the fluid status in the PICU, and it is still commonly used in critical pediatric patients⁽¹⁵⁾. It reflects the right ventricular filling pressure, and provides information about the intravascular volume⁽²⁸⁾. However, the feasibility and efficacy of measuring CVP are often questioned because of risks associated with its invasive nature, such as infection, pneumothorax, and hemothorax, as well as commercial differences. These all depend on personal assessments⁽²⁹⁾.

In recent years, more studies have found and emphasized the subjectivity and decreased reliability of CVP for detecting volume status⁽²⁹⁾. The correlation between the IVC diameter and the right atrial pressure was first described in 1979

by Natori *et al.*⁽³⁰⁾. Several adult studies have demonstrated that the IVC collapsibility index correlates well with CVP⁽¹⁸⁾. A study by Babaie *et al.*⁽²⁰⁾, aimed at predicting the fluid status in pediatric patients, evaluated 70 children ranging in age from one month to 12 years. The authors reported a negative correlation between CVP and the IVC collapsibility index, and found the mean IVC collapsibility index to be $35 \pm 16\%$. Another study by Mugloo *et al.*⁽³¹⁾ evaluated 50 newborns and reported that the IVC collapsibility index and CVP were negatively correlated. In a study of 50 spontaneously breathing children aged five to 18 years, Vaish *et al.*⁽¹⁹⁾ reported a positive correlation of CVP with the IVC diameters both during inspiration and expiration, and a negative correlation with the collapsibility index. They found that the IVC collapsibility index better reflected the intravascular volume status at the beginning of fluid resuscitation, whereas the IVC diameter did this better at the end. Long *et al.*⁽³²⁾ performed a prospective observational study, with fluid bolus therapy applied, on 33 sepsis patients in a pediatric emergency department. They performed echocardiography after five and 60 minutes, followed by fluid bolus therapy, and detected that the IVC collapsibility index had poor test characteristics for predicting fluid responsiveness in spontaneously ventilating children with sepsis. Finally, Orso *et al.*⁽³³⁾ published a review article that comprised a total of 31 studies on IVC collapsibility, IVC distensibility, and IVC diameters. The review included three pediatric studies where the results revealed that an ultrasound evaluation of the IVC diameters and its respiratory variations did not seem to be a reliable method for predicting fluid responsiveness.

Pediatric literature on IVC distensibility index

Positive-pressure ventilation elevates the pleural and right atrial pressure values. It also reduces the venous return to the heart by increasing the intrathoracic pressure during inspiration. These factors act on the diameter and distensibility of the IVC. Finally, the IVC diameter dilates during inspiration and contracts during expiration in an intubated patient, unlike in spontaneously breathing patients⁽³⁴⁾. Therefore, it is recommended that the IVC distensibility index be used instead of the IVC collapsibility index in patients undergoing positive-pressure mechanical ventilation⁽³⁵⁾. Pediatric data are limited, and the IVC distensibility index is a new term in pediatric practice. For this reason, both Babaie *et al.*⁽²⁰⁾ and Mugloo *et al.*⁽³¹⁾ used the IVC collapsibility index measurements in their studies on intubated patients under positive pressure. A study on mechanically ventilated adult patients in septic shock demonstrated that the IVC distensibility index values of greater than 18% were in favor of fluid deficit⁽³⁶⁾. Previous studies were conducted regarding the effectiveness of using the IVC distensibility index to predict fluid responsiveness in critically ill children⁽³⁵⁾. In a pediatric study, Basu *et al.*⁽³⁷⁾ compared the IVC distensibility index, CVP, and other common methods to assess the fluid status in mechanically ventilated pediatric patients that were seriously ill. There was no significant correlation between the IVC distensibility index and CVP. The study results showed that IVC distensibility had a good correlation with fluid overload, and might be useful to assess the degree of volume

Tab. 1. The aim, formulas, benefits and question marks for the IVC collapsibility index and the IVC distensibility index

	IVC collapsibility index	IVC distensibility index
Aim	Volume status assessment in spontaneously breathing patients	Volume status assessment in mechanically ventilated patients
Method	IVC images are acquired in the sagittal section. Images of the IVC draining into the right atrium are obtained while the probe is in the subxiphoid area and the liver is taken in the acoustic window.	
	Minimum IVC diameter on inspiration and maximum IVC diameter on expiration are measured.	Maximum IVC diameter on inspiration and minimum IVC diameter on expiration are measured.
Formula	(Maximum diameter on expiration – minimum diameter on inspiration) Maximum diameter on expiration	Maximum diameter on inspiration – minimum diameter on expiration Minimum diameter on expiration
Benefits	Quick, non-invasive, easy, repeatable, trustworthy and objective method for volume status evaluation ¹⁷	
Question marks	There are no well-determined limits for the IVC collapsibility index and distensibility index in the pediatric age group in the published literature. Pediatric intensivists still use limitations described for adult patients for managing fluid therapy (for IVC collapsibility index >50%, for IVC distensibility index >18%). Further studies on large groups of critically ill pediatric patients could help to determine ultrasonographically measured pediatric IVC index limits	
IVC: Inferior vena cava		

overload in patients. Bilgili *et al.*⁽³⁵⁾ performed a prospective study with 24 pediatric urological surgery patients under general anesthesia. They measured the cardiac index, the IVC distensibility index, and the internal jugular vein distensibility index before and after a passive leg raising maneuver. Patients were termed fluid responders if >10% increase was detected in the cardiac index after the maneuver. In the fluid responder group, the patients had higher IVC and internal jugular vein distensibility indices. The authors also noticed that the IVC distensibility index predicted fluid responsiveness in anesthetized pediatric patients. In an experimental animal study, Mendes *et al.*⁽³⁸⁾ determined the accuracy of the IVC distensibility index for evaluating fluid responsiveness in rats with acute respiratory distress syndrome. They observed that an IVC distensibility index threshold of less than 25% was associated with a positive response to volume expansion. Although the results have been contradictory, and the reference values have not been described well yet, recent studies show that the IVC distensibility index is a reliable measure of predicting fluid responsiveness in mechanically ventilated children⁽³⁵⁾. A summary which includes the aim, formulas, benefits and question marks for the IVC collapsibility index and the IVC distensibility index is shown in Table 1.

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Conclusion

In conclusion, the collapsibility and distensibility indices of the IVC are ultrasonographic measurement methods that are noninvasive, quick, radiation-free, and can be done at the patient's bedside. Despite the lack of certain and reliable reference values of the IVC diameters as well as the IVC collapsibility and distensibility indices, an increasing number of studies with large patient groups will contribute to the literature on pediatric patients. Although there are opposing views, considering the lost prestige and reduced popularity of CVP, we believe that these measurement methods to evaluate the volume status of critical pediatric patients are increasingly coming to the fore in intensive care units.

Conflict of interest

Authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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