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Caval Sonography in Shock

A Noninvasive Method for Evaluating Intravascular Volume in Critically Ill Patients

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 Invited paper

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Abbreviations

IVC, inferior vena cava

Sonography has traditionally been used to assess anatomic abnormalities. However, its value in evaluating physiologic characteristics has recently been recognized, particularly in the care of patients in shock. As the use of point-of-care sonography grows in critical care and emergency medicine, noninvasive assessment of intravascular volume status is increasingly being used to guide therapy of the critically ill.

Although intravenous fluid is often the initial treatment in hypotensive patients, aggressive volume resuscitation may be detrimental in some patients and in certain types of shock. Accurate diagnosis of shock state can be challenging because physical findings of hypovolemic, distributive, cardiogenic, and obstructive shock often overlap. Pulmonary artery and central venous pressure catheters, which provide physiologic data such as cardiac output and right atrial pressure, are time-consuming, invasive, and carry considerable risks. Central venous pressure has long been used to guide fluid management; however, data suggest that in critically ill patients, central venous pressure may not correlate with the effective intravascular volume.¹ Furthermore, invasive hemodynamic monitoring has not been shown to benefit patients.²

Given the importance of determining intravascular volume in shock, a rapid bedside sonographic examination can be instrumental in guiding medical management of critically ill patients. Multiple sonographic protocols now exist for the evaluation of shock, dyspnea, and cardiac arrest.^{3,4} This article will describe the use of sonography of the inferior vena cava (IVC) in the evaluation of patients in shock.

Physiology: IVC Parameters

The IVC is a compliant vessel that distends and collapses with pressure and volume changes. Although the absolute IVC size varies widely among healthy individuals and may not by itself be diagnostic, the maximal IVC diameter has been shown to be lower in patients with hypovolemia.⁵

A better indicator of intravascular volume is collapsibility of the IVC. As intrathoracic pressure decreases with inspiration, venous blood is pulled from the lower half of the body into the right atrium. This action causes a transient, but normal, decrease in the IVC diameter. With expiration, the IVC diameter increases and returns

to its baseline. These changes are known as respirophasic variability. The IVC collapsibility index, also known as the caval index, is defined as the difference between the maximal (expiratory) and minimal (inspiratory) IVC diameters divided by the maximal diameter. The caval index is used in spontaneously breathing patients to estimate right atrial pressure.^{6,7} In patients with minimal respirophasic collapse, having the patient inspire forcefully, or sniff, will differentiate between patients with poor inspiratory effort and those with elevated right atrial pressure. The sniff method may provide more accurate estimation of volume status; however, measurements taken during normal respiration are reasonably accurate as well.⁸

Recent guidelines from the American Society of Echocardiography support the general use of IVC size and collapsibility in assessment of volume status.⁹ Studies have suggested the use of specific parameters for maximal IVC diameter and caval index to predict volume status.^{6,8} In one of these studies, using 2 cm as the cutoff for the maximal IVC diameter resulted in good sensitivity and specificity for predicting elevated right atrial pressure.⁸ A caval index greater than 50% suggests a low volume state,⁶ especially in combination with a small IVC diameter. Conversely, a low caval index with a large IVC diameter suggests a high volume state.

Inferior vena cava size does not predict right atrial pressure in patients receiving mechanical ventilation.¹⁰ Mechanical ventilation reverses the hemodynamics of venous return during the respiratory cycle. During positive pressure inspiration, intrathoracic pressure is increased, impeding blood flow from the IVC to the right atrium. During expiration, intrathoracic pressure is lower, and venous return increases. In a patient with normal right atrial pressure, this cyclic venous return produces minimal variation of the IVC size during the respiratory cycle. When a patient is volume depleted, however, the right atrium and IVC become more compliant, and the IVC size increases with positive pressure inspiration. Assessment of the IVC has been used in mechanically ventilated patients to predict whether fluid expansion is expected to increase the stroke volume and cardiac output. The variation of the IVC in positive pressure ventilation, known as the IVC distensibility index, is the difference between the maximum and minimum IVC diameters divided by the minimum diameter. In contrast to IVC collapsibility, which indicates volume status, the distensibility index has been used to assess preload dependence and predict fluid responsiveness such that the absence of respiratory variation suggests that volume expansion is unlikely to be effective.^{11,12} Fluid responsiveness is an emerging and important concept in

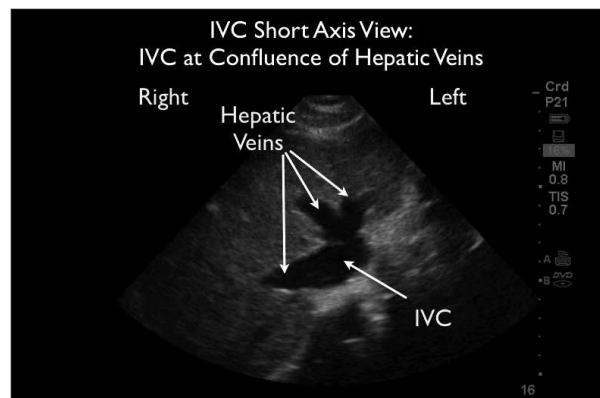
critical care that seeks to avoid unnecessary fluid administration, which may expose the patient to risks of volume overload, when a fluid challenge is not expected to improve hemodynamics and organ perfusion.

Anatomy and Scanning Technique

A low-frequency phased array transducer (3.5–5 MHz) is used to evaluate the IVC, which lies in the retroperitoneum to the right of the aorta. It is differentiated by its thinner walls and respiratory flow variation. The IVC passes posterior to the liver and is joined by the hepatic veins before it enters the thoracic cavity and drains into the right atrium. 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.^{6,8,12–14} Other studies measure the IVC at or near the junction with the hepatic veins.^{11,15–20} A study comparing commonly measured locations found that respiratory variation of the IVC at the junction with the right atrium did not correlate with variation at sites distal to the hepatic veins.²¹ 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.⁹

To image the IVC, the probe is placed in the subxiphoid 4-chamber position with the probe marker oriented laterally to identify the right ventricle and right atrium. As the probe is progressively aimed toward the spine, the convergence of the IVC with the right atrium will be seen. The IVC should be followed inferiorly, specifically looking for the confluence of the hepatic veins with the IVC (Figure 1). The IVC can also be evaluated in the long-axis

Figure 1. Short-axis view of the IVC.



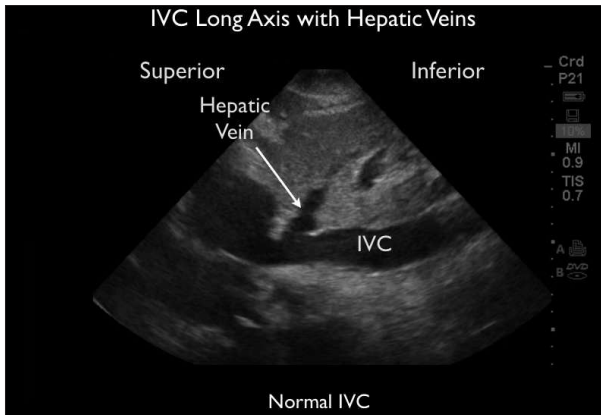
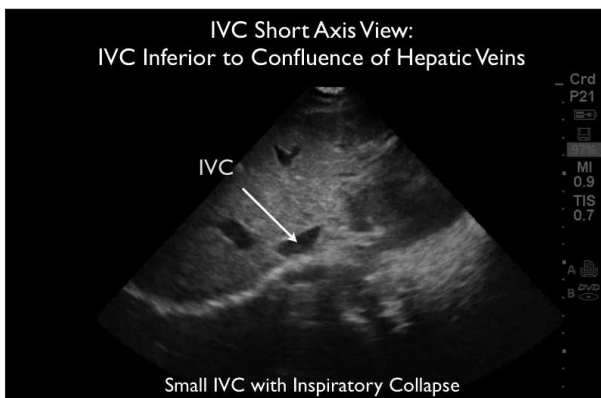


Figure 2. Long-axis view of the IVC.

plane. For this view, the probe is turned from a 4-chamber subxiphoid to a 2-chamber subxiphoid orientation, with the probe now in a longitudinal orientation (Figure 2). Although this view allows visualization of the IVC throughout the length of the hepatic segment, the true size of the IVC may be underestimated in the long axis due to a common error known as the cylinder tangent effect. This effect occurs when the ultrasound beam travels through the vessel longitudinally in an off-centered plane. One way to avoid underestimating the size of the IVC is to angle the probe laterally and medially until the greatest dimension is identified.

The diameter of the IVC should be measured perpendicular to the long axis of the IVC at end-expiration and end-inspiration. The finding of a small-diameter IVC with large inspiratory collapse (high caval index) correlates with low volume states. This phenomenon may be observed in hypovolemic and distributive shock states (Figures 3 and

Figure 3. Short-axis view of a small IVC with inspiratory collapse.

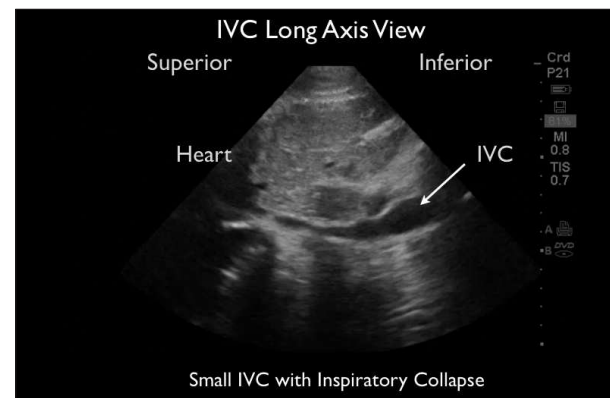


4 and Videos 1 and 2). Conversely, a large IVC with minimal collapse (low caval index) suggests a high volume state such as cardiogenic or obstructive shock (Figures 5 and 6 and Videos 3 and 4). Movement of the diaphragm, especially during forceful inspiration or sniffing, may displace the IVC relative to the probe, making it difficult to obtain comparative measurements at the same location. In the short axis, the probe may need to be angled inferiorly during inspiration to locate the site measured at expiration. In the long axis, displacement of the IVC may require angling inferiorly and/or laterally (to avoid tangential measurement). In either orientation, it is recommended to observe the changes of the IVC through several respiratory cycles.

M-mode Doppler sonography of the IVC can be used to graphically document the absolute size and dynamic changes in the caliber of the vessel during the patient's respiratory cycle in both short and long axes (Figures 7–10). It should be noted, however, that M-mode sonography may introduce inaccurate measurements due to the displacement of the IVC relative to the probe during inspiration. Movement of the IVC out of the plane of the M-mode cursor may appear as vessel collapse on the M-mode tracing. It is therefore recommended that M-mode sonography be used after adequately visualizing IVC variability in the B-mode to avoid inaccurate estimation of vessel size and collapse.

Further studies are needed to define normal IVC parameters such as size, collapsibility, and distensibility (in mechanically ventilated patients). Until then, assessment of IVC collapsibility is useful in the critically ill patient whose caval index approaches the extremes. Additionally, caval sonography can be repeated during resuscitation to evaluate improvement of these parameters.

Figure 4. Long-axis view of a small IVC with inspiratory collapse.



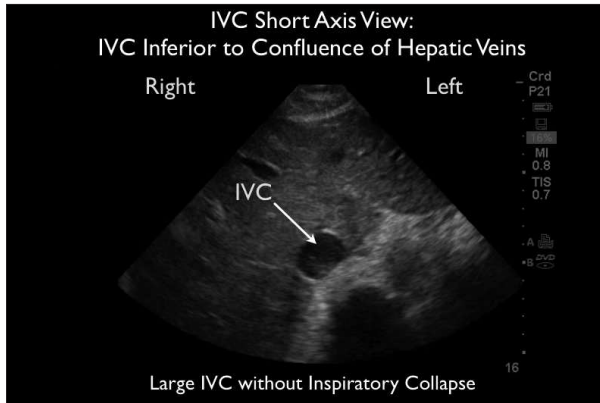


Figure 5. Short-axis view of a large IVC without inspiratory collapse.

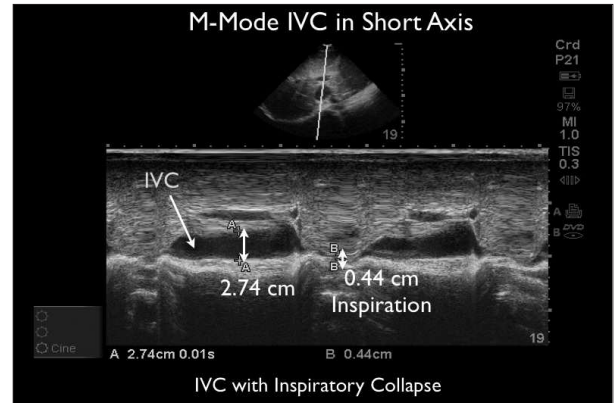
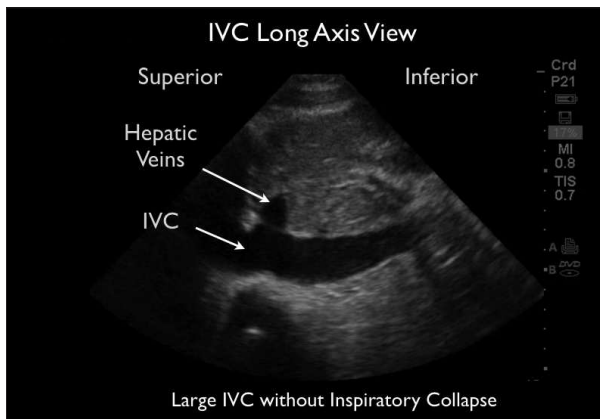


Figure 7. M-mode short-axis view of an IVC with inspiratory collapse.

Evidence

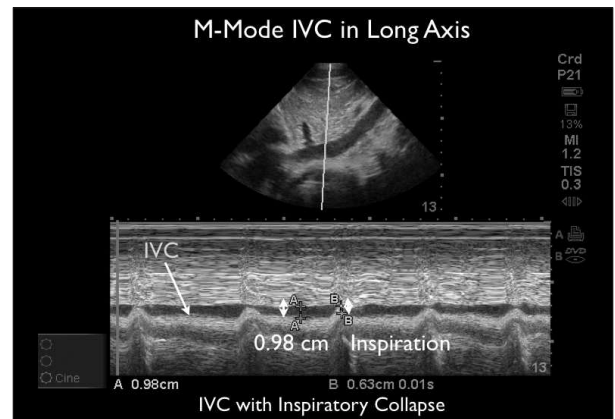
Incorporation of a goal-directed sonographic protocol including assessment of the IVC has been shown to improve the accuracy of physician diagnosis in patients with undifferentiated hypotension.²² In a recent prospective study, point-of-care sonography evaluating cardiac contractility and IVC collapsibility in patients with suspected sepsis was shown to increase physician certainty and alter more than 50% of treatment plans.²³ Inadequate dilatation of the IVC after a fluid challenge was more sensitive than blood pressure for identification of hypovolemia in trauma patients.²⁴ Another study in trauma patients showed the value of bedside caval sonography in evaluation of fluid status and resuscitation of critically ill patients.²⁵ A study in acutely dyspneic patients presenting to the emergency department showed that IVC sonography rapidly identifies patients with congestive heart failure and volume overload.²⁶

Figure 6. Long-axis view of a large IVC without inspiratory collapse.



Rather than relying on a single measurement of the IVC, it may be more useful to follow changes in vessel size and collapsibility over time in response to an intervention. Studies have shown a decrease in the IVC diameter and increased collapsibility after blood loss¹⁵ and fluid removal during hemodialysis.²⁷ In hypotensive emergency patients, volume resuscitation was associated with increases in the IVC diameter and less inspiratory collapsibility.¹⁴ Just as a single blood pressure measurement is an incomplete representation of the hemodynamic status of a patient, sonography of the IVC should be repeated after interventions or changes in clinical parameters. Monitoring of the IVC diameter during resuscitation is an emerging area of research, and further studies are necessary to determine the exact parameters to interpret IVC size and collapsibility.

Figure 8. M-mode long-axis view of a small IVC with inspiratory collapse.



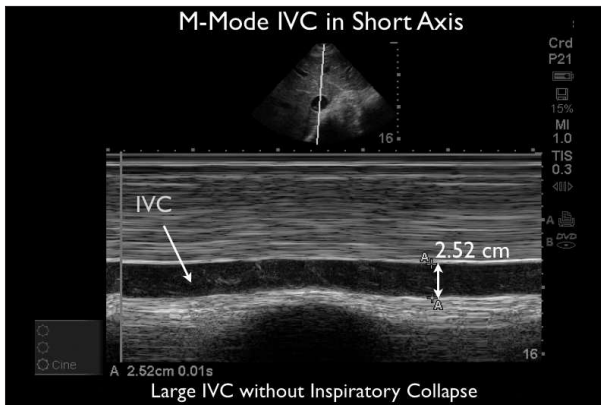


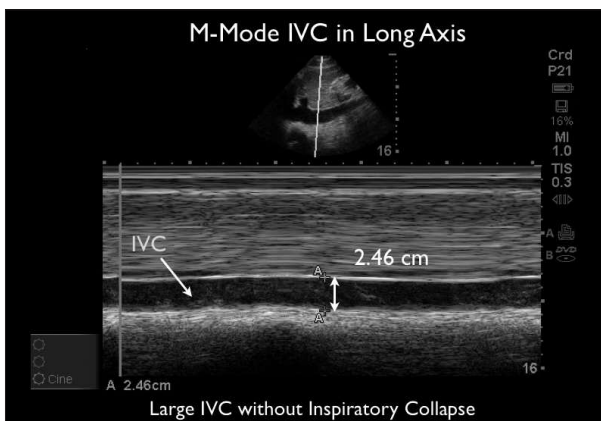
Figure 9. M-mode short-axis view of a large IVC without inspiratory collapse.

Pitfalls

The IVC should be followed to the junction with the right atrium to avoid misidentification with the aorta. Because a single long-axis view may be inaccurate, it is recommended to assess the IVC in both short and long axes. Inferior vena cava determinations should be made at or near the confluence with the hepatic veins. Measurements elsewhere may not reflect intravascular volume.

A dynamic evaluation of the degree of IVC collapse with inspiration may correlate better with the intravascular volume than a single static measurement of the vessel size. Inferior vena cava size does not predict right atrial pressure in patients receiving mechanical ventilation. Care should be taken to maintain adequate visualization of the IVC throughout the respiratory cycle because the probe and IVC may be displaced by diaphragmatic and abdominal wall movements. Overestimation of intravascular

Figure 10. M-mode long-axis view of a large IVC without inspiratory collapse.



volume may occur in conditions that impede flow to the right heart, including valvular abnormalities, pulmonary hypertension, and heart failure.

Interpretation of caval physiology is hindered by conditions that restrict the physiologic variability of the IVC, such as liver cirrhosis and fibrosis,²⁸ masses causing external compression, and elevated intra-abdominal pressure. Interpretation of the physiologic characteristics of the IVC should be done in context with the patient's clinical scenario and adjunctive data.

Conclusions

Determination of shock state in critically ill patients is challenging, but caval sonography may be a substitute for invasive hemodynamic monitoring. Assessment of the physiologic characteristics of the IVC provides a rapid distinction between low and high volume states and offers the clinician a rapid, noninvasive way to guide resuscitation in critically ill patients. In addition to caval sonography, focused echocardiography and lung sonography have been suggested by an increasing number of resuscitation sonography protocols to further evaluate patients in shock.

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