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Ultrasound Guided Volume Assessment Using Inferior Vena Cava Diameter

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Abstract: Ultrasound provides a rapid method of evaluating the emergency patient at the bedside by the treating physician. Besides being advantageous in eliminating or supporting a differential diagnosis in an emergency patient, bedside ultrasound can also rapidly evaluate physiology. This articles describes such a use of bedside ultrasound, the evaluation of the inferior vena cava size and collapsibility in the evaluation of shock states. The ultrasound procedure is described as well as how to integrate the information gained from this test into clinical practice.

Keywords: Ultrasound, clinical ultrasound, inferior vena cava diameter, shock evaluation, bedside sonography.

INTRODUCTION

Ultrasound has rapidly gained popularity in the emergency medicine setting because it is safe, rapid, non-invasive and can be brought to the bedside. Bedside ultrasound is not a complete radiological investigation but, rather, a focused evaluation to answer a clinical question. The inferior vena cava is a large vein that carries deoxygenated blood into the right atrium of the heart [1, 2]. Since the size and shape of the IVC is correlated to the central venous pressure and circulating blood volume, sonographic evaluation of the IVC is an instantaneous non-invasive measure of volume status [3]. The IVC is a very compliant vessel whose size varies with changes with intravascular pressure. Consequently, the IVC collapses with inspiration as the blood is pumped out of the IVC due to the negative pressure created by chest expansion. In healthy subjects breathing spontaneously, cyclic changes in thoracic pressure, result in collapse of the IVC diameter of approximately 50% [4]. Although there is a lack of universally accepted cutoffs, in healthy individuals, IVC diameter at inspiration ranges from 0 to 14mm at rest, and expiratory diameter of 15 to 20mm at rest [1]. An IVC collapsible index is defined as (IVCd exp – IVCd insp)/ IVCd exp. The closer the collapsibility index is to 0% or 100% the higher the likelihood that patient is volume overloaded or depleted, respectively [1].

CASE PRESENTATION

A 45 year old female with history of HIV and ESRD, presented to the Emergency department after missing her last hemodialysis appointment. She reported severe shortness of breath, cough, and nausea for the past several weeks. The review of systems was positive for weakness, chest pain, and orthopnea. The patient also admitted to using cocaine in the last 2-3 days. Her chest x-ray showed a diffuse bilateral infiltrate. Clinically, the differential diagnosis was consistent with volume overload as a result of missing a hemodyalysis treatment or pneumonia as a result of immunosuppression due to AIDS. Since the treatment for volume overload and pneumonia is very different, a bedside ultrasound exam was performed to assist in distinguishing the two diagnoses. A bedside limited ECHO showed a small pericardial effusion and global hypokinesis. More revealing, visualization of the IVC showed a small vessel that collapsed completely with inspiration, which is consistent with a low central venous pressure and not consistent with volume overload. The patient was diagnosed with pneumonia, treated with appropriate antibiotics, and hemodialysis was performed after admission to the hospital.

DISCUSSION

The IVC diameter is visualized with the patient in the supine position either using liver as an acoustic window or in the midline, inferior to the xyphoid, angling to the right (Fig. **1A**). The technique is performed by using a 2 to 4 MHz transducer such as curvilinear or cardiac probe, in the abdominal setting [1,5,6]. The cross section image of the IVC is visualized at the right atrial/hepatic vein/IVC junction and then rotated so that a long axis view of the IVC is obtained (Fig. **1B**). It is not necessary to instruct the patient on how to breathe, but a "sniff" can be used to accentuate the IVC collapse with respiration. The diameter on inspiration and expiration are measured approximately 1 cm distal to the IVC-hepatic vein junction where the anterior and posterior walls are clearly visualized [5] (Fig. **2**). Portions of the IVC can be difficult to visualize if there is a large amount of bowel gas. It may be necessary to use pressure on the transducer to move bowel out of the way [1,5,6]. The technique is non-invasive, rapid (exam time less than 1 minute), and can be part of any ultrasound guided exam such as FAST exams.

Shock is defined as decrease in tissue perfusion to a point at which it is inadequate to meet cellular metabolic needs. Common mechanisms of shock are hypovolemia, cardiac, distributive, and mechanical. Varying degrees of relative or absolute hypovolemia and myocardial dysfunction may exist in each category, particularly in sepsis [1, 6, 7]. Shock associated with sepsis may result from hypovolemia secondary to dehydration and vasodilatation, or a mechanical depression

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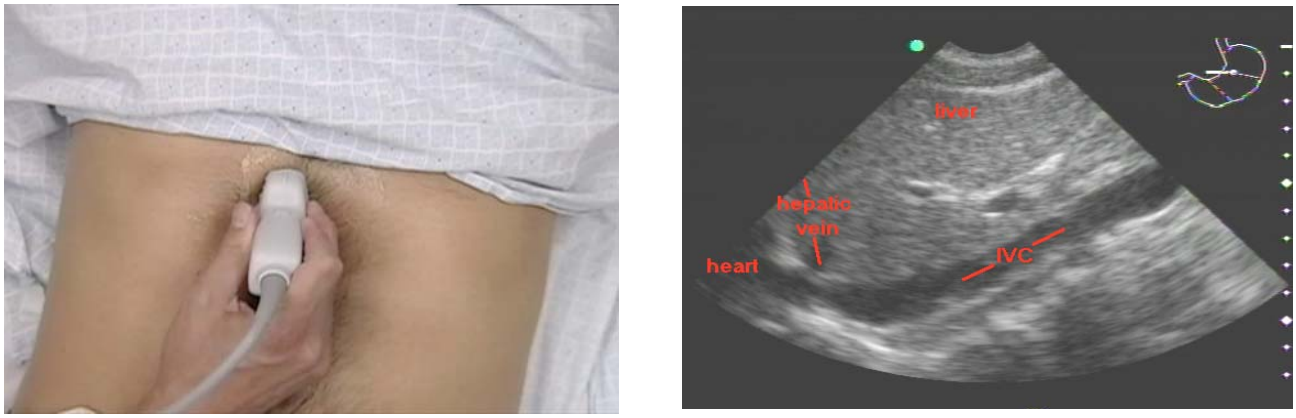

A **B**

Fig. (1). A: Cardiac probe in the subxyphoid location [5]. **B**: IVC, at the hepatic-IVC junction.

and distributive mechanism due to vasodilatation and microcirculatory dysregulation [7]. Mechanical causes of shock include tamponade, tension pneumothorax, and massive pulmonary embolism. Bedside evaluation of the IVC diameter should be used as an adjunct and in clinical context to further differentiate the type of shock since there can be significant overlap in polytrauma situations commonly encountered by emergency medicine physicians [5, 6]. Hypotension is observed in late decompensated shock. It occurs when compensatory mechanisms that maintain end-organ perfusion fail [4, 8].

Cardiac tamponade occurs when the intrapericardial pressure equals or exceeds right diastolic filling pressures. The classic physical findings of Becks triad, hypotension, muffled heart sounds and jugular venous distention (JVD) are late findings. Although right ventricular diastolic collapse has been shown to be the most common finding in tamponade on echocardiography, it can occur with or without right ventricular diastolic collapse [1, 2]. Severe hypovolemia can also cause diastolic ventricular collapse, but other clinical findings usually clarify the situation. In some cases when there is not a clear answer, the "sniff test" can help identify a tamponade [1]. A dilated IVC in the presence of pericardial effusion is highly suggestive of tamponade and warrants a pericardiocentesis [1]. The IVC should collapse by 50% or more of its diameter with sudden inspiration but will fail to do so in presence of tamponade [1]. Absence of IVC collapse with "sniff" is highly sensitive for tamponade when combined with a pericardial effusion.

Pulmonary embolism is another cause of shock, which can be difficult to identify. Bedside ultrasound can give an indication of massive PE by assessing the right ventricle to left ventricle dimension ratio, abnormal septal wall motion, and loss of normal IVC collapse [1, 2, 7]. A dilated IVC with dilated right ventricle or dilated right atrium indicates a right ventricular outflow obstruction highly suggestive of PE [1]. Massive PE can cause hemodynamic instability by rapidly increasing right ventricular preload and afterload while undefiled left ventricle leads to low perfusion pressures. This can lead to low (<50%) collapsibility index of IVC. Hence in a patient with hypotension, right atrium dilation and dilated IVC, massive PE is the likely culprit [1, 2, 7].

IVC diameter measurements can also assist in ongoing resuscitation by providing a means to measure Central Venous Pressure (CVP) non-invasively [8]. This can also be very valuable in trauma patients. They are more susceptible to shock from many different mechanisms, but hemorrhagic shock emerges as the etiology in the overwhelming majority of cases and can be rapidly fatal. Hemorrhagic shock usually follows excessive and often rapid blood loss due to vessel or organ injury, leading to baroreceptor activation, vasoconstriction, increased cardiac conduction, and increased heart rate [6]. This compensation for blood loss continues until these mechanisms are overwhelmed. Lyons *et al.* demonstrated that there is a significant correlation between both the change in IVCi and the change in IVCe during blood donation of 450 mL [6]. This change was approximately 5 mm in both the dIVCi and dIVCe and was consistent regardless of the initial diameter. This argues that a patient can be monitored for ongoing blood loss by serially measuring the IVCd. Implied is that the IVCd can be used as a measure of intravascular volume in response to resuscitation [3, 6, 9, 10]. Thus, serial measurements of IVCe can be used to assess for ongoing blood loss as well as a marker for response to treatment and prevention of overhydration [3, 6].

A small collapsed IVC indicates hypovolemia and warrants further fluid resuscitation [8] Cherix at al, demonstrated that during hemodialysis with fluid removal, postdialysis under hydrated patients according to IVC indices showed a decrease of mean arterial pressure and stroke volume, and an increase of heart rate. No such changes were observed in postdialysis normovolaemic and hypervolemic patients [9, 10].

Atkinson *et al*. discussed the use of IVC diameter as part of ACES protocol for patients with undifferentiated hypotension [11]. Their protocol consists of six windows including cardiac, peritoneal, pleural, inferior vena cave and aortic views with the goal to shorten the time period taken to establish a diagnosis and hence to deliver the most goal-directed therapy [11]. They concluded that the ACES protocol is a useful adjunct to clinical examination in patients with undifferentiated hypotension in emergency department. Table **1** summarizes their findings.

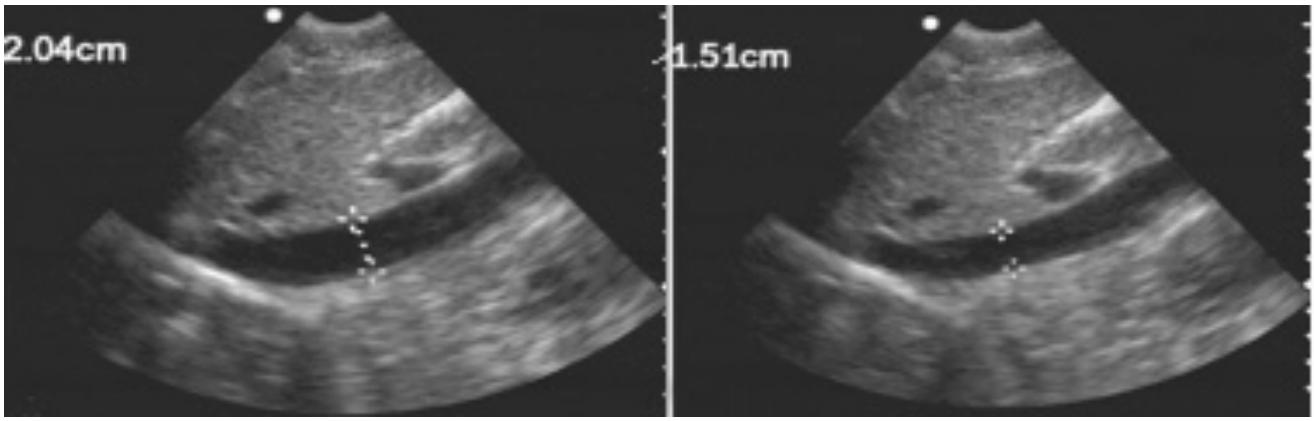

Fig. (2). IVC diameter measured on expiration (**A**) and on inspiration (**B**) [5].

Table 1. Abdominal and Cardiac Evaluation with Sonography in the Hypotensive Patient [11]

Category of shock	Cardiac Function	IVC	Treatment
Septic	Hyperdynamic left ventricle Hypodynamic in late sepsis	Narrow IVC, Collapses with inspiration	IV fluid, Pressors
Cardiogenic	Hypodynamic left ventricle	Dilated IVC, little or no collapse with inspiration	Ionotropic medications
Hypovolemic	Hyperdynamic left ventricle	Narrow IVC Collapses	Evaluation of cause, IV fluids and blood replacement
Obstructive (cardiac tamponade)	Pericardial effusion Diastolic collapse right ventricle	Dilated IVC, no collapse with inspiration	Pericardiocentesis
Obstructive (pulmonary embolus)	Dilated right ventricle Dilated right atrium	Dilated IVC Minimal collapse	Thrombolytics

AAA, abdominal aortic aneurysm; IVC, inferior vena cava.

CONCLUSION

The use of ultrasound-guided IVC assessment for fluid management in critically ill emergency patients has not yet been validated in controlled studied but when used in conjunction with other information such as the ACES protocol, can be a valuable tool.

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Received: January 24, 2010 Revised: June 14, 2010 Accepted: June 14, 2010

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