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The Use of Ultrasonography in Circulatory Failure

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Abstract: This chapter is meant to consolidate the information presented in the previous chapters and apply the information to the hemodynamically unstable patient. Real-time bedside ultrasonography performed by intensivists trained in basic ultrasound techniques helps to diagnose the etiology of shock, provides information about the patients' volume status, and has become indispensible in placing central catheters.

Keywords: Right ventricle, ultrasound, Cor pulmonale, ventricular wall stress, pulmonary hypertension.

The treatment of the shock state depends upon the underlying etiology of circulatory failure. Ultrasound provides rapid assessment of hemodynamically unstable patients. Indeed, real-time bedside ultrasonography performed by the treating intensivist helps to distinguish different shock states and allows for early goal-directed therapy. Armed with knowledge and performance in basic critical care ultrasonography, shock due to obstruction, i.e. pulmonary embolism or cardiac tamponade, due to hypovolemia, or of distributive origin (such as septic shock), can be distinguished in minutes. Ultrasonography is a portable, reproducible, and most importantly, a non-invasive modality that continues to gain popularity in intensive care units (ICU). This article will review the use of ultrasound in circulatory failure and describe an approach to its use in the ICU.

We should note that several protocols have been developed for use of rapid assessment in the emergency department, specifically for patients in shock with and without a history of trauma [1-3]; these will not be reviewed here. Moreover, ultrasound techniques have been described in detail in other sections of this supplement and will not be restated here. While we believe rapid bedside evaluation of the shock state using ultrasound is very beneficial, it is in no way meant to substitute for a thorough history and clinical examination while resuscitative and therapeutic maneuvers are begun. Prior history of GI bleeding, heart disease, the presence of heart murmurs, extra heart sounds, pericardial rubs, elevated neck veins, or unilateral absence of air entry on examination remain invaluable, and the ultrasound is meant to complement the history and clinical examination.

Occasionally, ultrasonography will diagnose the etiology of shock unequivocally. For example, the finding of pericardial fluid and tamponade physiology, or the visualization of a thrombus in one of the main pulmonary arteries necessitates intervention. However, it will become obvious from the following discussion that the etiology of shock will more likely be ascertained by the ultrasound examination of several organs in a coordinated fashion. It should also be stressed that while searching for abnormal ultrasound findings in the pursuit of an etiology of shock is essential; a normal examination of a key organ system is just as useful as it rules out components of the differential diagnosis. For example, a hypotensive patient with a known underlying malignancy and a clear chest radiograph with a normal appearing right ventricle on ultrasound, virtually rules out a massive pulmonary embolus. Implicit in the discussion of ultrasound usage in shock patients, is the dynamic nature of symptoms and signs. This is a rapidly changing situation secondary to both the initial insult and its treatment. As such, we use ultrasound to first aid in the diagnosis of shock, and then to serially evaluate the therapeutic interventions [4].

The most logical place to begin the ultrasound examination of the hypotensive patient is the heart. A number of views are obtained: parasternal long and short, apical four-chamber and subcostal [5]. The objective is to assess the function of cardiac structures and to determine the most likely etiology of the shock state. We assess LV size and function, RV size and function, gross valvular abnormalities and the pericardial space, along with the size and variation of the IVC with respiration. A normal or hyperdynamic LV without RV dysfunction is suggestive of either a hypovolemic state and/ or distributive shock. This is very helpful early in the diagnosis of shock states as the contractility of the heart may rapidly change following changes in afterload and preload conditions, i.e. volume rescuscitation or the use of vasopressors, or from sepsis-induced myocardial dysfunction.

One of the central questions in the hypotensive patient is whether or not a volume challenge increases preload and therefore cardiac output. As discussed by Kitakule and Mayo, the variation of the IVC in patients passive on mechanical ventilation is very helpful. The typical profile of hypovolemia is that of a small hypercontractile LV, a flattened IVC, and absence of lung rockets, the latter described in the chapter by Hakimisefat and Mayo.

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An uncommon finding of dynamic left ventricular outflow tract obstruction from hypovolemia may masquerade as a low flow state with elevated pulmonary capillary wedge pressure and low cardiac index when a pulmonary artery catheter in used. This may lead the intensivist to believe that the hypotension is due to poor LV function and prompt iontropic support with preload reduction. This phenomenon is most commonly seen in elderly patients with history of hypertension and is best appreciated with 2-D echocardiography. The treatment is in fact the opposite of a cardiogenic shock, and volume administration along with heart rate reduction and the use of phenylepherine for blood support are warranted.

Pericardial fluid in the critically ill hypotensive patient demands careful analysis. First, the distinction between pericardial and pleural fluid must be made. However a moderate to large echo free space surrounding the heart circumferentially with evidence of either right ventricular diastolic collapse or right atrial systolic collapse is suggestive of tamponade. Drainage can be performed under echocardiographic guidance [6].

Acute valvular dysfunction as an etiology for hypotension is not common in the MICU. A flail mitral valve leaflet or a very stenotic appearing aortic valve with decreasing escursion may be noted with basic cardiac ultrasound. Color Doppler is essential for the complete diagnosis of valvular disease, but is beyond the basic bedside critical care ultrasound. We believe that competence in basic critical care ultrasonography does not include the use of color or spectral Doppler. The intensivist should be able recognize that a valvular abnormality exists, and then seek consultation with a more advanced echocardiographer [5].

While auscultation of the lungs continues to be performed in the ICU, one study found that in contrast to chest auscultation and plain film chest radiography, lung ultrasonography had a greater than 90% diagnostic accuracy. This is due to the difficulty in performing adequate lung examination in critically ill patients who are frequently intubated and mechanically ventilated. Lung ultrasound can provide objective data [7]. An airless lung on physical examination points to the presence of massive pleural effusion or pneumothorax or pneumonia. These can be easily distinguished by bedside ultrasonography as they have different patterns (see chapters on pleural and lung diseases) alleviating the need for a portable X-ray film. Hypotension with a clear chest radiograph along with the presence of bilateral sliding lung and A-line pattern could represent obstructive shock, such as a pulmonary embolus. Evaluation of the right ventricle, the IVC, and a compression study of the lower extremities for DVT is warranted. As Alaverdian and Cohen describe, a dilated hypokinetic RV with evidence of pressure overload may indicate a pulmonary embolus. Careful attention to the thickness of the RV free wall may allow distinction of acute versus chronic elevations in pulmonary pressures. The finding of DVT on ultrasound examination of the lower extremities makes the diagnosis of massive PE much more likely. A rare cause of hemodynamic collapse is a tension pneumothorax usually accompanied by severe dyspnea and hypoxemia. As discussed by Chandra and Narasimhan in the chapter on pleural ultrasound, a pneumothorax can be ruled out in seconds by the absence of lung sliding.

Oiguria or anuria often accompanies hypotension. The coordinated ultrasound examination will aid in diagnosis and treatment. The proper position of the Foley catheter in the bladder can quickly be confirmed. Absence of lung rockets on lung examination and a flattened IVC in the setting of a hypercontractile LV suggest the absence of pulmonary edema and the presence of hypovolemia; fluid resuscitation in this situation is appropriate [4].

In cases of circulatory collapse the ultrasound aids not only in detecting the etiology, but also in resuscitation and management. Rapid insertion of central venous lines has been shown to be easier and safer with the use of ultrasound, while the associated complication rate of venous central line placement is greater than 15% [8, 9]. A randomized study of 450 critical care patients who underwent real-time ultrasound-guided cannulation of the internal jugular vein were compared with 450 patients in whom the landmark technique was used. Access time (skin to vein) and number of attempts were significantly reduced in the ultrasound group. In the landmark group, puncture of the carotid artery occurred in 10.6% of patients, hematoma in 8.4%, hemothorax in 1.7%, pneumothorax in 2.4%, and central venous catheter-associated blood stream infection in 16%, which were all significantly increased compared with the ultrasound group. Indeed, The Agency for Healthcare Research and Quality presently recommends the use of ultrasound for central venous placement as one of their 11 practices to improve patient care [10].

Circulatory collapse is common in the MICU and its rapid determination of its etiology and subsequent treatment is necessary for improved outcomes. Time-honored practices of measuring CVP and the use of the pulmonary artery catheter for determination and therapeutic decision making have undergone scrutiny. Bedside critical care ultrasonography helps the intensivist to rapidly assess organ systems to determine etiology of shock. Moreover, real-time ultrasonography is portable, repeatable, and performed by the treating intensivist. Critical care ultrasonography has a steep learning curve, but can be learnt at the bedside in a relatively short time period. The use of ultrasound in the diagnosis of shock is gaining popularity and serves to complement the clinical examination.

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