The Role of Echocardiography in Hemodynamic Assessment of Septic Shock

Matthew J. Griffee, MD, Matthias J. Merkel, MD, PhD, Kevin S. Wei, MD

Echocardiography was originally developed in the 1950s, but it was not until the late 1980s that a few pioneering intensivists advocated echocardiography as the preferred first-line technique for evaluation of patients with hemodynamic instability. In the past decade, interest in applications of echocardiography in the intensive care unit (ICU) arena has greatly increased. Clinical research questioning the diagnostic value of central venous and pulmonary artery (PA) pressure data, coupled with advances in portable ultrasound technology, have stimulated interest in echocardiography for hemodynamic assessment. Experts in the United States, Canada, and Europe argue passionately for incorporating echo training into ICU fellowship requirements.

There are many strengths of echo for assessment of hemodynamic instability, including:

- Speed: qualitative assessment of all chambers and the performance of both ventricles can be done within minutes
- Anatomic breadth: valves and pericardium are included in the echo assessment
- Noninvasive (transthoracic echocardiography [TTE] is completely noninvasive; transesophageal echocardiography [TEE] does require esophageal intubation)
- Intuitive: structure and function are assessed simultaneously, and many people prefer visual assessment to analysis of PA catheter numbers

KEYWORDS
- Echocardiography • Septic shock • Resuscitation
- Fluid therapy • Cor pulmonale
Diastolic dysfunction, hyperdynamic obstruction, and acute right heart failure can be diagnosed. These disorders may be difficult to diagnose using right heart catheterization alone, potentially leading to counterproductive treatment. Nevertheless, echo and central venous monitoring are complementary techniques. PA or transthoracic thermodilution catheters offer advantages compared with echo:

- Measurement of venous oxygen saturation (SvO₂), lung water, and continuous cardiac output
- Continuous monitoring.

This article introduces the techniques of hemodynamic assessment using echocardiography, highlights insights provided by echocardiography into the effects of sepsis on the heart, outlines credentialing and competency standards, and refers interested readers to resources for training and further education.

**FUNDAMENTALS OF ECHOCARDIOGRAPHY**

An ultrasound transducer contains crystals that emit sound waves when exposed to an electric field. The crystals are arranged in a matrix and send sound waves serially. Most of the time, the crystal is not vibrating; rather, it detects returning sound waves. These are produced when the sound waves moving through the patient encounter an interface between tissue layers with different acoustic properties or which block sound transmission altogether. Because the sound returns sooner if it is reflected from a more shallow source, the timing of reflected waves correlates with the depth of tissue interfaces. The returning sound causes the crystal to vibrate, which generates an electric signal. The pattern of returning sound impulses is processed electronically to provide a visual representation of the sonographic anatomy. Details can be found in a reference textbook.

**ECHOCARDIOGRAPHY EQUIPMENT**

The ultrasound transducer for TTE has a square surface, rather than the elongated rectangle of the transducer used for vascular imaging. There is an inverse relationship between sound wave frequency and depth of penetration, with an advantage in terms of better resolution with high frequency. Higher-frequency, lower-depth probes are used for vascular imaging with ultrasound. By contrast, an echocardiography transducer emits a variety of frequencies to provide optimal resolution at a range of depths. It also uses a high frame rate to capture cardiac motion and display it smoothly. By contrast, using the abdominal preset of the software menu produces blurred images of the beating heart. It is useful for an ICU to have a dedicated machine, available 24 hours per day, to make echocardiography a readily available diagnostic tool for unstable patients.

**EXAMPLE OF A FOCUSED ECHOCARDIOGRAPHY STUDY FOR HEMODYNAMIC ASSESSMENT**

This section describes the cross-sectional anatomy revealed by standard transducer positions, or “echo windows,” for hemodynamic evaluation of an ICU patient. Typical clinical scenarios for this application of ultrasound include patients who present with shock of unknown cause and patients who do not respond to standard resuscitation for presumed septic shock. The goal is to expeditiously rule in or rule out several potential causes of acute hemodynamic compromise.
The following example of an imaging sequence lists pertinent considerations for each window:

1. Parasternal long axis (Fig. 2)
   a. Evaluate global left ventricular (LV) systolic function. Does wall motion and thickening seem moderately or severely compromised?
   b. Evaluate mitral and aortic valves for gross anatomic abnormality, such as flail leaflet, vegetation, or severe restriction of movement.
   c. Evaluate right ventricular (RV) free wall for contractility and RV size relative to LV size. The right ventricle should appear smaller than the left ventricle.
   d. Evaluate for pericardial effusion. A pericardial effusion will appear as an echo-free space outside the epicardium, and will insinuate between the descending aorta in the far field and the posterior border of the left ventricle at the base of the heart. A pleural effusion will be located deep to the descending aorta.

2. Parasternal short-axis views (Fig. 3)
   a. Evaluate RV size and function. Watch septal motion in systole. Evaluate for increased RV systolic pressure, which may result in flattening of the interventricular septum, causing the left ventricle to have a D shape, instead of a circular cross section.
   b. Examine LV systolic function. Inspect inward excursion of the LV endocardium during systole, and note the thickening of the LV wall as it contracts. Evaluate for segments of the left ventricle that do not move as well as others. Categorize LV systolic function as normal, moderately impaired, or severely impaired.

3. Apical 4-chamber view (Fig. 4)
   a. Evaluate global LV systolic function. Does systolic function seem normal, or is it moderately or severely impaired? Observe LV cavity at end systole. Is there complete or near-complete obliteration, and extremely vigorous systolic wall excursion? This pattern is consistent with hyperdynamic function, low afterload, and inadequate preload.
b. Inspect the mitral valve and tricuspid valve for any gross pathology (flail leaflet, vegetation).

c. Evaluate RV size. Compare RV area with LV area. Estimate whether RV size is less than 60% of LV size (normal) vs between 60% and 90% of LV area (moderate dilation) or more than 90% of LV area (severe dilation).

d. The degree of tricuspid annular systolic excursion correlates with RV ejection fraction (EF). If RV systolic function is normal, the plane of the tricuspid valve is expected to move toward the apex by 2 cm in systole.


5. Returning to the apical 4-chamber view, the probe is rotated clockwise to obtain the apical 2- and 3-chamber views for evaluation of LV systolic function in additional cross-sectional planes.

6. Subcostal view (Fig. 5)
   a. Evaluate for pericardial effusion
   b. In suspected tamponade, evaluate for RV collapse in diastole and right atrial collapse in systole
   c. Compare size of right and left ventricles (see relative RV size assessment, discussed earlier).

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**Fig. 2.** Parasternal long-axis view. This view is obtained by placing the probe alongside the left upper sternal border, directing the marker to the patient’s right shoulder. (From Otto CM. Textbook of clinical echocardiography. Philadelphia: Saunders Elsevier; 2009. p. 35; with permission. Original source credit [in caption of figure]: From Otto CM. Echocardiographic evaluation of valvular heart disease. In: Otto CM, Bonow R, editors. Valvular heart disease: a companion to Braunwald’s heart disease. Philadelphia: Elsevier/Saunders; 2009; with permission, copyright Elsevier, 2009.)
7. Intrahepatic inferior vena cava (IVC) window. Assess volume status by measuring respiratory variation in IVC diameter (see section on volume responsiveness).

8. Lung bases. Image each lung base and diaphragm to evaluate for massive pleural effusion. Patient positioning is often adequate with the patient supine; however, poor views can often be improved with rotation of the patient 30% to 60% toward the left lateral position. If clinically safe, it may also improve acoustic windows to temporarily reduce positive expiratory end pressure (PEEP) during the examination. The examination sequence described here is an example of a focused echocardiographic evaluation. Detailed information with excellent illustrations is available from standard textbooks.
Patients in septic shock require volume expansion in the initial phase of resuscitation to prevent hemodynamic collapse. However, after preload is optimized, further fluid loading may not only fail to increase oxygen delivery but may also cause harm (eg, it may lead to pulmonary edema [PE] and bacterial translocation across the gut).12 Traditional indices of preload, such as central venous pressure (CVP) and pulmonary artery pressure (PAP), have been found to be unreliable in predicting fluid responsiveness (defined as the potential to increase cardiac output significantly in response to a fluid challenge).13 Because echocardiography is an alternative to invasive monitoring, there has been an interest in finding sonographic correlates of pulse pressure variation in patients with septic shock.14

The most useful echocardiographic parameters for assessment of fluid responsiveness are respiratory variation of vena cava diameter and of stroke volume.14 As for any clinical prediction tool, it is important to understand the prerequisite criteria for applying these measurements, because there are multiple potential confounding factors. Patients must be in a controlled mode of ventilation, with a tidal volume of at least 8 mL/kg, and with no spontaneous respiratory effort. Similarly, patients must be in sinus rhythm. For indices of IVC size, patients must have normal intraabdominal pressure.14 In addition, patients with acute cor pulmonale undergoing mechanical ventilation may have dynamic signs of fluid responsiveness (pronounced pulse pressure variation and IVC collapse) due to adverse effects of increased pleural and pulmonary pressure during inspiration on the dilated, failing right heart, but fluid challenge may worsen the RV failure and fail to increase cardiac output.15

PRELOAD/PREDICTION OF VOLUME RESPONSIVENESS

Patients in septic shock require volume expansion in the initial phase of resuscitation to prevent hemodynamic collapse. However, after preload is optimized, further fluid loading may not only fail to increase oxygen delivery but may also cause harm (eg, it may lead to pulmonary edema [PE] and bacterial translocation across the gut).12 Traditional indices of preload, such as central venous pressure (CVP) and pulmonary artery pressure (PAP), have been found to be unreliable in predicting fluid responsiveness (defined as the potential to increase cardiac output significantly in response to a fluid challenge).13 Because echocardiography is an alternative to invasive monitoring, there has been an interest in finding sonographic correlates of pulse pressure variation in patients with septic shock.14

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In 2004, 2 groups reported a positive correlation between the magnitude of respiratory-induced changes in IVC diameter and volume responsiveness in patients requiring with septic shock.\(^{16,17}\) Both groups measured fluctuations in IVC diameter associated with respiration before and after a fluid bolus and observed a highly significant correlation between variation in IVC diameter and the increase in cardiac output after the bolus.\(^{16,17}\) Patients were categorized as responders if cardiac index increased by at least 15% after the bolus. An intriguing and potentially clinically useful finding was that there appeared to be a clear cutoff value for initial IVC size variation and the response to volume expansion. Feissel and colleagues\(^ {16}\) reported that using 12% as a threshold value for IVC size variability, responders to a fluid bolus could be predicted with positive and negative predictive values greater than 90%. Barbier and colleagues\(^ {17}\) found that a threshold variability in IVC size of 18% predicted the response to volume expansion with sensitivity and specificity of 90%.

Superior vena cava (SVC) diameter is also affected by the large fluctuations in intrathoracic pressure caused by positive pressure variation. A disadvantage of monitoring SVC caliber variation is that it requires TEE. However, because the SVC is intrathoracic, a potential advantage is less confounding from elevations of intraabdominal pressure. Vieillard-Baron and colleagues\(^ {18}\) noted a clustering of baseline SVC collapsibility between responders (with SVC collapse of 60% or more) and nonresponders (in whom SVC varied by 30% or less). This finding results in a specificity of 100% and

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**Fig. 5.** Subcostal view. The transducer is placed just caudal to the xiphoid, with a flat angle, turned to scan into the left side of the thorax. The first structure encountered by the ultrasound from this view is the right ventricle. Sliding to the midline will reveal the inferior vena cava (IVC) and aorta. (From Otto CM. Textbook of clinical echocardiography. Philadelphia: Saunders Elsevier; 2009. p. 47, copyright Elsevier, 2009; with permission.)
a sensitivity of 90% for predicting a significant increase in cardiac output when the SVC collapsibility exceeds 36%.18

Another ultrasound technique for assessing volume responsiveness relies on Doppler measurements of stroke volume. Fluctuations in stroke volume associated with ventilator cycling are greater in the hypovolemic patient than in the completely resuscitated patient.19

Providing a temporary test dose of volume expansion can be accomplished with passive leg raising, which briefly redistributes blood pooled in the lower extremities to the central circulation. If stroke volume is measured before and after the position change, the intensivist can then evaluate the hemodynamic effect of increasing preload. Advantages of this technique are that it remains valid even if the patient is breathing spontaneously and even if the patient is not in sinus rhythm.20

A potential area for further research is to compare clinical outcomes of resuscitation protocols with versus without echocardiographic assessment of volume responsiveness to guide restoration of cardiac output.

ECHOCARDIOGRAPHIC DIAGNOSIS OF SEPSIS-INDUCED MYOCARDIAL DYSFUNCTION

Echocardiography provides a detailed, comprehensive evaluation of systolic performance and relies on pattern recognition to identify or exclude common categories of cardiac dysfunction (Table 1). The triage echo for shock should include interpretation of right and left ventricular performance (see later section). Furthermore, when systolic function is impaired, global hypokinesis should be distinguished from regional wall motion abnormalities. Echocardiography for patients who remain in shock despite volume expansion and norepinephrine is important because it may lead to changes in therapy.

Echocardiographic studies of cohorts of patients with septic shock and investigations with a longitudinal design have provided insight into the incidence, natural history, and mechanism of sepsis-induced cardiac dysfunction. Highlights include

1. Although cardiac output may be normal or even high in early septic shock, systolic function is often impaired. Furthermore, myocardial depression may only become apparent when afterload is restored with norepinephrine.21,22 Impaired systolic function has been found in patients with low, normal, and even increased cardiac output.23
2. Approximately 20% of patients with septic shock have isolated diastolic dysfunction. Cardiac filling and relaxation are abnormal, whereas systolic function is preserved.24,25
3. Septic myocardial dysfunction may reflect impaired adrenergic responsiveness, rather than deranged myocyte contractile function.26 Many clinical studies use the term contractility imprecisely, as a synonym for decreased EF. EF should not be confused with contractility, because EF is influenced by preload. When a more exacting, preload-independent index of contractility was measured in patients in septic shock, investigators noted preserved contractility. In contrast, most patients exhibited impaired adrenergic responsiveness, defined as a dose-dependent increase in cardiac output with escalating doses of dobutamine. In the course of 10 days, contractility changed little, whereas adrenergic responsiveness improved steadily.26 The parallel in vitro finding of an impaired response to β-agonists despite normal intrinsic contractile function has been reported when cardiomyocytes have been exposed to sepsis serum.27,28
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<thead>
<tr>
<th>Cardinal Findings</th>
<th>Clinical Scenario</th>
<th>Implications/Treatment</th>
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<tbody>
<tr>
<td>Hypovolemia</td>
<td>Significant collapse of IVC/SVC with respirations; obliteration of LV cavity at end systole</td>
<td>Prior to fluid challenge; ongoing volume losses; severe vasodilatation; internal bleeding</td>
</tr>
<tr>
<td>Impaired Systolic Function</td>
<td>Moderately to severely reduced LV systolic wall thickening and excursion; dilated IVC with no respiratory variation</td>
<td>Evidence of low cardiac output; low urine output; PE</td>
</tr>
<tr>
<td>RV failure</td>
<td>RV size equal to or larger than LV size; apex of heart dominated by right ventricle</td>
<td>Suspected PE; history of chronic obstructive pulmonary disease; acute respiratory distress syndrome (ARDS)/acute lung injury</td>
</tr>
<tr>
<td>Diastolic Dysfunction (not measured directly on basic ICU echo, but suspected by deduction given echo findings and clinical scenario)</td>
<td>Thick left ventricle with normal or hyperdynamic function; no evidence of systolic dysfunction; evidence of PE</td>
<td>History of hypertension; aortic stenosis</td>
</tr>
<tr>
<td>Tamponade</td>
<td>Pericardial effusion; right atrial or RV collapse; marked respiratory variation of pulse pressure, systolic pressure, and IVC size</td>
<td>Heart instrumentation; thoracic surgery; disease with possible pericardial manifestations; transient responses to fluid challenges</td>
</tr>
<tr>
<td>Hyperdynamic Function</td>
<td>LV hypertrophy, vigorous systolic function, small LV cavity size, obliteration of LV cavity at end systole, tachycardia</td>
<td>Patient with poorly controlled hypertension, acute hypovolemia, and tachycardia</td>
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</table>
4. Sepsis-induced cardiac dysfunction seems to resolve completely, regardless of the severity of the dysfunction in the midst of the illness. The expected course is gradual improvement, with complete recovery within 4 weeks (among those who survive the episode of sepsis).1

PRACTICAL EVALUATION OF LV SYSTOLIC FUNCTION

The most common and important technique for evaluation of systolic function for ICU echocardiography is by visual estimate.5 There are 2 components: amount of endocardial border excursion toward the center of the left ventricle and increasing wall thickness during contraction. Expert echocardiographers with extensive training and experience can accurately estimate small changes over time in estimated EF and have the ability to distinguish between normal and mildly impaired, or between mildly and moderately impaired systolic function by visual estimate. By contrast, competency in basic echocardiography is defined by the ability to categorize the systolic function as normal, moderate dysfunction, or severe systolic dysfunction.5

Classification of decreased systolic function as global versus regional can also be defined on expert and basic levels. The American Heart Association (AHA) defined standard views and segmental anatomy and nomenclature for the description of regional wall motion abnormalities.29 The basic-level echocardiographer should distinguish between global and regional systolic dysfunction, but scoring and precise localization of regional dysfunction mandates expert consultation.

Two peculiar patterns of systolic function are of particular relevance in ICU echocardiography. In transient apical ballooning (also referred to as Takotsubo) there is hyperdynamic basal function with impaired midchamber function and aneurysmal dilation of the apex.30 The distribution of dyskinesis does not follow the anatomic distribution associated with an episode of an acute coronary syndrome. Transient apical ballooning is often preceded by severe emotional stress (eg, loss of spouse, a life-threatening diagnosis) and presents with troponin elevation and ST-segment deviation. Epicardial coronary artery disease (CAD) is absent and the apical ballooning resolves in most cases.30

In dynamic left ventricular outflow tract (LVOT) obstruction, abnormally increased contractile function results in obliteration of the upper LV cavity before end systole, blocking further ejection, and thereby reducing stroke volume.31 This may be associated with mitral regurgitation. Whereas systolic function is abnormally increased, diastolic performance of the hyperdynamic myocardium is reduced, resulting in reduced filling, especially in case of tachycardia. If hyperdynamic function with an underfilled ventricle is not recognized, counterproductive treatment may be used to treat presumed systolic dysfunction. Empiric administration of an inotrope results in worsening diastolic function, lower stroke volume, and LVOT obstruction earlier in systole, and may lead to myocardial ischemia. When dynamic obstruction is recognized, treatment includes stopping inotropes, administering volume, increasing afterload with phenylephrine, and, in some cases, administering β-blockers. Recognizing hyperdynamic LV function with end-systolic LV chamber obliteration will thus lead the intensivist to make dramatic changes in hemodynamic management.31

ECHOCARDIOGRAPHIC IDENTIFICATION OF ACUTE RV FAILURE

Echocardiography is essential to identify and monitor acute RV failure in bedside triage of the unstable patient. Discovery of RV failure may lead to significant changes in treatment. For example, the unexpected finding of severe, acute right heart dilation and failure may trigger an evaluation for thromboembolism, lead to changes of PEEP
or other ventilator settings contributing to high airway pressure, or reverse a working diagnosis of hypovolemia.

The components of critical care echocardiography (CCE) to diagnose RV failure as a potential cause of shock are RV distention at end-diastole and the sign of RV pressure overload in systole. Because the right ventricle has a complex three-dimensional shape, its volume cannot be calculated accurately from cross-sectional diameter measurements using a simple geometric model. However, Jardin and colleagues showed that the relative area of the right ventricle compared with the area of the left ventricle in the 4-chamber view can be used as a surrogate marker of RV dysfunction. The normal RV area/LV area is 0.36 to 0.6; moderate RV dilation corresponds to an RV/LV ratio between 0.7 and 0.9, and severe RV dilation results in an area equal to or greater than that of the left ventricle. The relative areas of the right and left ventricles should be estimated or measured in an apical 4-chamber or subcostal view.

The sign of RV pressure overload, septal flattening or paradoxic septal motion, is also based on a comparison between the right and left ventricles. Because the interventricular septum is shared by both ventricles, its relative position (leftward or rightward) and shape (flattened or curved) are determined by the pressure difference between the left and right ventricles. Normally, systole and diastole occur in concert in the right and left ventricles, and the septum thickens toward the center of the left ventricle along with the LV free wall throughout systole. However, RV pressure overload results in prolongation of RV systole into the period of LV relaxation. The pressure gradient across the septum (with high pressure in the right ventricle at end systole and low pressure in the relaxing left ventricle) results in deviation of the septum toward the left ventricle, while the rest of the left ventricle is continuing to move outwards in diastole. After RV systole is completed, and LV pressure exceeds RV pressure, the septum returns to its normal position, presenting a convex surface into the RV cavity. Septal dyssynergy, the abnormal alternating shift in septal position, can be identified visually from multiple windows, and it can be quantified using the eccentricity index, which is the ratio of anteroposterior diameter of the left ventricle (which is parallel to the septum and is not affected by septal shift) and the medial-lateral diameter of the left ventricle (which is perpendicular to the septum and is compressed during septal shift).

Identifying RV failure by echo in an unstable patient may have prognostic and therapeutic implications. In a registry of 1416 patients with acute PE and overall mortality of 3.3%, the subset of patients with RV/LV area greater than 0.9 had a 6.6% mortality, compared with 1.9% for patients with RV/LV ratio less than 0.9. If acute pulmonary hypertension is associated with RV dilation and failure, potentially modifiable factors include acidosis, PEEP, and hypoxemia. In a retrospective analysis of a database of 352 patients with acute respiratory distress syndrome (ARDS), Jardin and Vieillard-Baron noted a higher frequency of acute cor pulmonale (defined by echo criteria) with higher plateau pressure (Ppl). There was no significant increase in mortality for the group with Ppl of 27 to 35 cm H2O compared with the group with Ppl 18 to 26 cm H2O when patients with acute cor pulmonale were excluded. Among patients with these ranges of Ppl who did manifest acute cor pulmonale, mortality was increased in the group with higher Ppl.

Sepsis-induced myocardial dysfunction can affect the right as well as the left ventricle. Just as LV dysfunction may be unmasked by starting a vasoconstrictor infusion, so too can RV failure become manifest only after institution of mechanical ventilation. Therefore, a cardinal virtue of a dedicated ICU echocardiography machine is the ability to repeat limited bedside evaluations after significant changes in support. Sepsis-induced RV dysfunction is expected to have the same natural history as LV
failure, including reversibility to normal function within 10 days. If the diagnosis of acute cor pulmonale is made in a patient in septic shock based on echo criteria (RV dilation and septal flattening), further volume expansion may serve only to exacerbate the RV dysfunction/dilatation, even though the left ventricle may appear empty. Expert opinion–level recommendations include fluid restriction, adjustment of ventilator settings to reduce airway pressure, correction of hypoxemia, and use of vasoconstrictors for maintaining coronary perfusion. Volume expansion, on the other hand, proves detrimental by exacerbating RV dilation and failure. One pitfall of using dynamic indicators of fluid responsiveness without evaluation of right heart function is that positive pressure ventilation may exacerbate acute cor pulmonale during each inflation, yielding false positive pulse pressure variation and IVC collapsibility.

**TAMPOONADE, AN ALTERNATIVE DIAGNOSIS TO SEPSIS IN ACUTE HEMODYNAMIC INSTABILITY OF UNKNOWN CAUSE**

Because pericardial tamponade is life-threatening and has been reported in 2% to 10% of ICU echo examinations, evaluation of the pericardium should be included in even a limited examination of patients in shock. High-risk ICU populations include patients who have had cardiac surgery, coronary catheterization, PA catheter placement, and penetrating chest trauma. Pericardial effusions appear as echo-free spaces surrounding the heart. Pericardial effusions can be distinguished from pleural effusions based on location and distribution: a pericardial effusion extends into the reflection of pericardium interposed between the descending aorta and the base of the left ventricle; the contour of a pleural effusion courses posterior to the descending aorta. In addition, a large pericardial effusion typically surrounds the heart, whereas a pleural effusion does not. However, in the case of heart surgery or recurrent pericardial effusion, a loculated effusion can form in a pocket, bordered by adhesions between the parietal and visceral pericardium. Such a loculated effusion can compress a single chamber, even at low volumes, because of the restricted volume within the pocket, and may require surgical treatment because adhesions may prevent percutaneous drainage.

Because the pericardium adapts to effusions that accumulate slowly by dilating, but develops sharp increases in pressure with rapidly expanding effusions (because it is inelastic), the absolute size of a pericardial effusion does not determine whether tamponade physiology is present. Instead, the diagnosis depends on evidence of increased intrapericardial pressure. Examples of this evidence include right atrial collapse occurring when the atrioventricular (AV) valves are closed and RV diastolic collapse. In addition, the finding of a fixed, engorged IVC caliber supports the clinical diagnosis.

**ECHO TRAINING FOR INTENSIVISTS**

National board requirements, guidelines of national organizations, and international echo training pathway standards have been published. Table 2 compares standards and guidelines. Recent trends in defining competency in ICU applications of echo include an emphasis on achieving competency, rather than specifying the duration of training or a precise number of studies, and interest in incorporating basic ICU echo into training requirements for fellows.

A uniquely designed investigation regarding the rate of gaining proficiency in hand-held ultrasonography involved medical residents with less than 1 hour of formal teaching on principles of ultrasound followed by 1:1 bedside teaching by a sonographer. Based on comparison with a comprehensive echocardiogram, the technical
<table>
<thead>
<tr>
<th>Organization and Reference</th>
<th>Duration of Training/Pathway Goal</th>
<th>Number of Examinations</th>
<th>Additional Requirement</th>
<th>Required Supervision</th>
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<td>Basic CCE</td>
<td>Competency-based</td>
<td>“The goal of the statement is to describe the minimal standards for critical care ultrasound as a guide for the intensivist to achieve proficiency”</td>
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<tr>
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<td>Competency-based</td>
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<td>American College of Cardiology/AHA <a href="http://www.echoboards.org">J Am Coll Cardiol 2003;41(4):687–708</a></td>
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<td>150 performed</td>
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<td>Level 3</td>
<td>750</td>
<td>300 performed</td>
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<td>WINFOCUS <a href="http://www.echoboards.org">Cardiovasc Ultrasound 2008;6:49</a></td>
<td>Emergency echo</td>
<td>Competency-based. Level 1 is all standard views and common abnormalities; level 3 is subspecialty echocardiographers</td>
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| The Role of Echocardiography |

377
quality of hand-held ultrasound and the interpretive skill were rated by a cardiologist. Residents performed examinations in the course of inpatient rotations. Performance improved as the number of supervised examinations increased, and linear regression of the adequacy of examinations suggested that between 20 and 30 examinations would be required for trainees to obtain studies with acceptable technical and interpretive accuracy.

TRAINING RESOURCES FOR INTENSIVISTS

The American College of Chest Physicians, the Society of Critical Care Medicine, the Society of Cardiovascular Anesthesiologists, and the American Society of Echocardiography have annual workshops with a focus on echocardiography training for non-cardiologists, and upcoming conferences are listed on their respective websites. Contact information and additional resources are listed in Appendix 1.

RELIABILITY OF FOCUSED ICU ECHO USING HAND-HELD AND COMPACT PORTABLE DEVICES

The performance characteristics of focused echocardiography by nonspecialists using hand-held or limited ultrasound machines depends on multiple factors, including

- Amount of training in image acquisition and interpretation
- Sophistication of the device (eg, whether the device has harmonic imaging, controls for adjusting gain and focus, and color Doppler)
- Criteria for considering the examination successful (the definition of success covers a wide spectrum in the literature, from simply revealing diagnoses not found by physical examination alone, to finding all significant abnormalities from an 18-item list)
- Patient setting (ventilated vs not ventilated, surgical ICU vs medical ward).

Not surprisingly, the variety of reports of the diagnostic accuracy of portable ultrasound by beginners reflects the influence of the many variables involved. For example, if portable ultrasound is deemed successful simply by extending the physical examination, it has obvious relevance. Portable ultrasound reduces the number of major cardiac findings missed on physical examination from 43% to 21%.43 By contrast, stringent comparison of beginner performance compared with that of experts reveals pitfalls of novice echocardiographic interpretation of potential clinical significance. After 20 hours of training and 20 supervised examinations, internal medicine residents and expert cardiologists used hand-held ultrasound to examine 300 patients who had undergone comprehensive echo studies.44 From a list of 18 clinically significant findings, residents missed 23%, compared with 14% by experts ($P = .02$). Findings missed more often by trainees using portable echo included pericardial effusions, RV dysfunction, and regional wall motion abnormalities. The conclusion that the limited portable ultrasound in the hands of trainees is no substitute for a formal comprehensive echo is neither controversial nor surprising. However, it is notable that the residents’ interpretations achieved the same specificity, positive predictive value, and negative predictive value as those of expert cardiologists.44

A far more practical study design limits the scope of the study and the modalities of the scanning, with the intention of using bedside ICU echo in goal-directed resuscitation. A proof-of-principle study by Manasia and colleagues45 involved 6 intensivists using a hand-held device after only 10 hours of echo training. The intensivists limited the echo to two-dimensional views from 2 to 4 windows, and focused on LV function
and size, volume status, and presence or absence of significant pericardial effusion. Using the comparison of a subsequent examination by an expert cardiologist, the intensivists’ readings were correct in 84% of patients. Echo led to changes in treatment in 37% of the subjects and provided new diagnostic data (without changing treatment) in 48% of patients. Similarly, Vignon and colleagues described performance in ICU residents after an 8-hour training limited to two-dimensional imaging. Interpretation was limited to LV size and function, RV dilation, pericardial effusion, and pleural effusion. Residents were able to evaluate 93% of 366 clinical questions and showed close agreement with the interpretations of expert echocardiographers.

SUMMARY

The role of echocardiography in assessing unstable ICU patients with suspected, or known, septic shock has been discussed. The key points are

- Echocardiography is complementary to other monitors of hemodynamics. Positive aspects of echocardiography include noninvasiveness, rapid results, and the potential for comprehensive cardiac assessment.
- Dynamic signs of preload responsiveness, such as IVC collapse, are easily measured, and are more informative than filling pressures.
- Echocardiography can be used to identify and to follow the progress of sepsis-induced cardiac dysfunction, which is common. In addition, echocardiography may reveal isolated diastolic dysfunction. In some cases, unexpected echocardiographic findings lead to major changes in therapy.
- Consensus descriptions of competency in basic and advanced CCE have been published recently, and CCE will likely be formally incorporated into ICU training programs soon.

REFERENCES

29. Cerqueira MD, Weissman NJ, Dilsizian V, et al. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart: a statement for healthcare professionals from the Cardiac Imaging Committee of the Council


APPENDIX 1: RESOURCES FOR ECHOCARDIOGRAPHY TRAINING FOR INTENSIVISTS

The American College of Chest Physicians holds annual national workshops in critical care ultrasonography, which includes echocardiography for diagnosis of the cause of shock. These workshops are open for members, nonmembers, and trainees, and involve small-group, hands-on teaching in ultrasonography. Web site: http://www.chestnet.org (accessed September 20, 2009).


Innovative Critical Care Ultrasonography is a company led by Yanick Beaulieu, MD, an intensivist-cardiologist in Montreal, which offers seminars on a regular basis and also offers on-site seminars (they travel to hospitals to train departments or practices). The Web site provides information on seminars, traveling seminars, and also on software for learning ICU echocardiography. Web site: http://www.iccuimaging.ca (accessed January 22, 2010).