Bedside Ultrasonography in the ICU*

Part 2

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This is the second of a two-part review on the application of bedside ultrasonography in the ICU. In this part, the following procedures will be covered: (1) echocardiography and cardiovascular diagnostics (second part); (2) the use of bedside ultrasound to facilitate central-line placement and to aid in the care of patients with pleural effusions and intra-abdominal fluid collections; (3) the role of hand-carried ultrasound in the ICU; and (4) the performance of bedside ultrasound by the intensivist. The safety and utility of bedside ultrasonography performed by adequately trained intensivists has now been well demonstrated. This technology, as a powerful adjunct to the physical examination, will become an indispensable tool in the management of critically ill patients.

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Key words: bedside ultrasonography; cardiac function; central line cannulation; critically ill; hand-carried ultrasound; ICU; paracentesis; thoracocentesis; transesophageal echocardiography; transthoracic echocardiography

Abbreviations: ASD = atrial septal defect; EF = ejection fraction; FAST = focused assessment by sonography in trauma examination; HCU = hand-carried ultrasound; IABC = intra-aortic balloon counterpulsation; IE = infective endocarditis; LA = left atrial/atrium; LV = left ventricular/ventricle; PAC = pulmonary artery catheter; PFO = patent foramen ovale; RA = right atrial/atrium; RV = right ventricular/ventricle; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography

The pericardium is a potential space that may be filled with fluid, blood, pus or, uncommonly, air. Echocardiography is the test of choice for the diagnosis of pericardial disease. In the ICU setting, the most common clinical indication for assessment of the pericardial space is suspected tamponade. The presence of fluid in this space is detected as an echo-free space. Pericardial fluid is usually easily detected with transthoracic echocardiography (TTE). The parasternal long- and short-axis and apical views will usually reveal the effusion. In many critically ill patients with suboptimal TTE image quality, the subcostal view will often be the only adequate window available to detect the presence of a pericardial effusion. In those ICU patients with poor acoustic windows and in the postcardiac surgical setting, transesophageal echocardiography (TEE) may be needed to assess the pericardial space adequately. Echocardiography also allows for the safe performance of pericardiocentesis.1,2

Cardiac tamponade is commonly encountered in the ICU, and its diagnosis requires a high index of suspicion. The most common causes of cardiac tamponade in the ICU are listed in Table 1. Echocardiographic two-dimensional signs of tamponade are a direct consequence of the increased pericardial pressure that will cause diastolic collapse of one or more cardiac chambers (usually right sided first) [Fig 1]. Usually, the right ventricular (RV) free wall collapse is seen in early diastole, and right atrial (RA) wall collapse is seen in late diastole.3 This latter sign is sensitive but not specific for tamponade. It is, however, specific for a hemodynamically significant effusion if the RA collapse lasts longer than a third of the R-R interval.3,4 In poststernotomy patients, tamponade may be missed by TTE (even in cases where
imaging quality seems adequate), as hematomas causing selective cardiac chamber compression are often in the form of loculated clots located in the far field of the ultrasound beam in the posterior heart region (even when the anterior pericardium is left open). The RA and RV may be spared in such cases secondary to postoperative adhesions or tethering of the RV to the chest wall anteriorly. In some circumstances, echocardiographic signs of tamponade may be very subtle or even absent, so one must keep in mind that the diagnosis of tamponade remains a clinical one and that the echocardiographic signs must be analyzed in conjunction with the clinical findings.

### Complications After Cardiac Surgery

Bedside echocardiography has proved to be of particular value in the management of patients with hemodynamic instability in the cardiothoracic ICU. TTE is often severely limited in this group of patients. TEE is thus the modality of choice in this setting, as it provides detailed information that can help determine the cause of refractory hypotension. The most frequent echocardiographic diagnoses encountered in this population of patients are left ventricular (LV) and/or RV failure, tamponade, hypovolemia, and valvular dysfunction. A number of studies have investigated the indications and impact of echocardiography (mostly TEE) in the hemodynamically unstable cardiac surgical patients. Schmiedlin et al demonstrated that a new diagnosis was established or an important pathology excluded in 45% of 136 patients after cardiac surgery. TEE had a therapeutic impact in 73% of cases. The main indications for the TEE in this study were assessment of LV function (34%), unexplained hemodynamic deterioration (29%), suspicion of pericardial tamponade (14%), and cardiac ischemia (9%). Reichert et al performed TEE in hypotensive patients after cardiac surgery (n = 60). LV failure was found in 27% of patients, hypovolemia in 23%, RV failure in 18%, biventricular failure in 13%, and tamponade in 10%. Comparison with invasive hemodynamic parameters showed agreement on diagnosis (hypovolemia vs tamponade vs cardiac failure) in only 50% of the cases. Echocardiography identified two patients with tamponade and six patients with hypovolemia not suspected by standard hemodynamic data. In five patients with hemodynamics suggestive of tamponade, unnecessary reoperation was prevented as TEE ruled out this diagnosis. Costachescu et al also demonstrated the superiority of TEE compared to conventional monitoring with pulmonary artery catheters (PACs) in diagnosing and excluding significant causes of hemodynamic instability in postoperative cardiac surgical patients.

### Table 1—Common Causes of Cardiac Tamponade in the ICU

<table>
<thead>
<tr>
<th>Cause</th>
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<tr>
<td>Myocardial or coronary perforation secondary to catheter-based intervention (ie, after endovenous pacemaker lead insertion, central line placement, or percutaneous coronary interventions)</td>
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<tr>
<td>Compressive hematoma after cardiac surgery</td>
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<tr>
<td>Proximal ascending aortic dissection</td>
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<tr>
<td>Blunt or penetrating chest trauma</td>
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<tr>
<td>Complication of myocardial infarction (ie, ventricular rupture)</td>
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<tr>
<td>Uremic or infectious pericarditis</td>
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<td>Pericardial involvement by metastatic disease or other systemic processes</td>
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![Figure 1](image-url) Cardiac tamponade. Top: Transthoracic parasternal long-axis view demonstrating the presence of a large circumferential pericardial effusion (*) with evidence of early diastolic RV collapse (arrow). Bottom: Transthoracic apical four-chamber view of the same patient showing the large pericardial effusion (*) and late diastolic collapse of the RA (arrow). Diastolic collapse of the RV and RA is concordant with the presence of tamponade physiology.
Infective Endocarditis

Infective endocarditis (IE) is a common presenting diagnosis or complication in ICU patients. IE has been reported to be the second most common indication for performance of echocardiography in the ICU. In the critically ill patient, multiple indwelling catheters, parenteral nutrition, severe underlying disease, altered GI mucosal permeability, and prolonged mechanical ventilation increase the likelihood of bacteremia and subsequent endocarditis. Classical clinical findings suggestive of endocarditis are uncommon in this patient population, particularly those with acute IE. Echocardiography is an excellent test for the noninvasive diagnosis of endocarditis. Fowler et al diagnosed endocarditis in 25% of patients with Staphylococcus aureus bacteremia referred for TEE. Only 7% of these patients had physical findings suggestive of endocarditis prior to the TEE. As the consequences of untreated endocarditis are devastating and often ultimately fatal, it is of utmost importance that this diagnosis and its complications be recognized promptly and treated appropriately. The echocardiographic features typical for IE are as follows: (1) an oscillating intracardiac mass on a valve or supporting structure or in the path of a regurgitant jet or an iatrogenic device, (2) intracardiac abscesses, (3) new partial dehiscence of a prosthetic valve, or (4) new valvular regurgitation. Sensitivity for the echographic diagnosis of endocarditis has been reported to be 58 to 62% and 88 to 98% for TTE and TEE studies, respectively. In the ICU, the sensitivity of the TTE for the diagnosis of endocarditis is poorer because the quality of the transthoracic study is commonly suboptimal. In addition, TEE has special benefits for small vegetations and prosthetic valves. TEE has also been clearly shown to be superior to TTE in diagnosing complications of endocarditis such as aortic root abscess, fistula, and ruptured chordae tendinae of the mitral valve. TEE in the ICU for suspicion of IE should be reserved for the following: (1) cases where the clinical likelihood of endocarditis is high and a TTE finding is negative, (2) for suspected prosthetic valve endocarditis, (3) to assess complications in known cases of endocarditis, and (4) for cases of Staphylococcus aureus bacteremia when the source is unknown or blood culture results remain positive despite antibiotic therapy.

Assessment of the Aorta

In the ICU setting, use of bedside echocardiography for assessment of suspected aortic complications provide many advantages over CT or aortography: there is no need for IV contrast, there may be less time delay, there is no need for transportation of the critically ill patient, and cardiac morphology and function can be evaluated at the same time. Aortography has for many years been the “gold standard” for the investigation of suspected injuries of the aorta. The advent of noninvasive modalities including CT scan, MRI, and TEE and their excellent sensitivity and specificity to diagnose aortic pathologies has decreased the need for aortograms.

Suspected aortic pathologies can be encountered in different ICU settings. The aorta may need to be imaged to assess for the presence of dissection, rupture, aneurysm, aortic debris, or aortic abscess. TTE is a good initial imaging modality for evaluation of the proximal aorta (ascending aorta and arch). However, the descending thoracic aorta cannot be adequately assessed and visualized with this modality, and this is a significant limitation of the TTE window. Because of the close anatomic relationship between the thoracic aorta and the esophagus, TEE allows a unique visualization of the entire thoracic aorta. As discussed in Part I of this article, there exists a “blind” spot in the distal portion of the ascending aorta and the proximal portion of the transverse aorta where imaging can be suboptimal.

Patients presenting with suspected aortic dissection need emergent diagnosis and treatment. TEE, CT, and MRI have been advocated for evaluation of suspected aortic dissection. Nienaber et al compared all three modalities and found that they had similar sensitivities (98%); however, MRI had a higher specificity than TEE (98% vs 77%). A limitation of this study was that single-plane TEE was used. With multiplane TEE, the specificity is improved, > 90%. In the Multicenter European Cooperative Study, TEE was demonstrated to be superior to both CT and aortography for the diagnosis of aortic dissection (sensitivity of 99%). A negative TEE finding even in a high-risk population has high negative predictive value. Emergent aortic imaging is indicated in the assessment of patients with blunt and penetrating chest trauma. These patients are at high risk of life-threatening aortic injuries, including traumatic dissection and rupture, and prompt diagnosis and treatment are required.

Additional very helpful features that TEE provides in the evaluation of aortic pathology are the ability to detect extension of the dissection in the proximal coronary arteries, the presence of pericardial or mediastinal hematoma/effusion, the presence, severity, and mechanism of associated aortic valve regurgitation, the point of entry and exit between the true and false lumen, the presence of thrombus in the false lumen, and ventricular function. In suspected thoracic aortic disease cases where TEE findings are...
equivocal or negative, other imaging modalities such as aortography, CT, or MRI should still be performed in addition to TEE.

**Assessment for Intracardiac and Intrapulmonary Shunts**

In critically ill patients, clinical suspicion for an intracardiac or intrapulmonary shunt will most often be raised in the context of unexplained embolic stroke or refractory hypoxemia. In such cases, the presence of a right-to-left shunt needs to be excluded. Common origins of right-to-left shunt are atrial septal defect (ASD) or patent foramen ovale (PFO) at the cardiac level, and arteriovenous fistula at the pulmonary level. A PFO is present in 25 to 30% of the normal population. Usually, a PFO only allows minimal and intermittent right-to-left shunting. But in situations where the RA pressure is raised and exceeds left atrial (LA) pressure, the PFO can widen and significantly increase the importance of the right-to-left shunt with resultant significant hypoxemia. In the critically ill patient, this increase in right-sided atrial pressure can occur from pulmonary hypertension such as seen with ARDS and pulmonary embolism, RV failure (from infarction or pulmonary hypertension), and from severe tricuspid regurgitation that is often seen in the ICU for a variety of reasons. Patients with PFO and persistent refractory hypoxemia despite mechanical ventilation and hemodynamic manipulation may sometimes need to have catheter-based septal defect closure devices inserted.

To be able to detect the presence of such a shunt at the bedside, a contrast study is often needed, as the shunt is usually not well visualized with two-dimensional echocardiography alone. Color-flow imaging will somewhat increase the detection rate of intracardiac shunt, but usually only when the shunt is large. A contrast study should therefore always be performed when evaluating a patient with unexplained embolic stroke or refractory hypoxemia. Agitated saline solution is usually used for this purpose; it is a simple and easy to use contrast at the bedside. Approximately 0.5 mL of air is mixed with 10 mL of normal saline solution, which is then vigorously agitated back and forth between two syringe connected to the patient by a three-way stopcock. After an adequate echocardiographic view of the RA and LA cavities has been obtained, the agitated saline solution is forcefully injected into the venous circulation. After injection, the contrast is seen in the vena cava, RA, RV, and the pulmonary artery. In the absence of a shunt, only a minimal amount of contrast should be expected to be seen in the left-sided cavities, as most of the microbubbles from the agitated saline solution are not able to pass though the pulmonary capillaries (Fig 2). If an intracardiac shunt is present, such as an ASD or PFO, left-sided contrast will be observed immediately after right-sided opacification and the contrast will be seen going through the interatrial septum (Fig 2). Performance of a Valsalva maneuver by the patient during contrast injection will increase the sensitivity of the bubble study to detect right-to-left shunting. In a patient receiving mechanical ventilation, a maneuver equivalent to a Valsalva may be performed by inducing sudden release of a sustained

**Figure 2. Microbubble study.** Top: A negative bubble study finding. A transthoracic apical four-chamber view shows the right-sided cardiac chambers completely opacified by microbubble contrast, but no contrast is seen crossing in the left-sided cavities. In the absence of a shunt, no contrast should be expected in the left-sided cavities, as most of the microbubbles from the agitated saline solution are not able to pass though the pulmonary capillaries. Bottom: Positive bubble study finding. The same transthoracic apical four-chamber view in a patient shows an intracardiac shunt present (ASD type). Left-sided contrast is observed immediately after right-sided opacification with the contrast being seen going through the interatrial septum. Performance of a Valsalva maneuver by the patient during contrast injection will increase the sensitivity of the bubble study to detect right-to-left shunting.
airway pressure previously achieved by inflating the lungs manually. This maneuver will reverse the atrial transseptal gradient and may help uncover a PFO that would not have been seen otherwise. Right-to-left shunting can also be caused by the presence of pulmonary arteriovenous fistulas. These are often associated with end-stage liver disease (hepatopulmonary syndrome). With this type of shunt, contrast is seen to appear in the LA from the pulmonary veins instead of through the atrial septum (best detected by TEE, which can usually visualize all four pulmonary veins). The characteristic of the intrapulmonary vs intracardiac shunt is that there is a longer delay (three to five cardiac cycles) between appearance of contrast from the right- to left-sided cavities in the presence of an intrapulmonary shunt.12

In the postmyocardial infarction period, cardiogenic shock can develop because of ventricular septal defect and resultant left-to-right shunt. The echocardiographic examination will reveal a disrupted ventricular septum with a high-velocity left-to-right shunt. This kind of shunt can usually be well visualized without use of contrast. The diagnosis can usually be established by two-dimensional and Doppler TTE in approximately 90% of cases.32 Penetrating cardiac trauma is often associated with intracardiac and extracardiac shunts, and TEE is becoming the obvious tool for perioperative early identification of occult shunts.3 Identification of these shunts is of utmost importance in these critically ill patients, as missing them may lead to cardiac tamponade and rapid death. TEE has been shown to be superior to both angiography and TTE to visualize these lesions.33–35

**Source of Embolus**

In the setting of acute unexplained stroke, echocardiography will often be required to determine if a potential embolic source of cardiac origin is present.36,37 TEE examination is the modality of choice for this purpose.36,37 Possible cardiac sources of emboli to the arterial circulation include LA and/or appendicular thrombus, LV thrombus, thoracic atheromatosis, and right-sided clots (RA, RV, vena cava) combined with a right-to-left intracardiac shunt (leading to a “paradoxical embolus”). Cardiac tumors and vegetations are other potential sources of emboli from cardiac origin that need to be considered.

In critically ill patients with atrial fibrillation or flutter in whom cardioversion is considered, performance of TEE will be very helpful for evaluating the LA and appendage for the presence of thrombus. If no intracardiac clots are documented, cardioversion can then be performed with minimal embolic risks.

**USE OF CONTRAST AND HARMONIC TECHNOLOGY TO ENHANCE TRANSTHORACIC EXAMINATIONS WITH POOR IMAGE QUALITY IN THE CRITICALLY ILL PATIENT**

Approximately 30% of patients will have suboptimal endocardial delineation by fundamental imaging.38 Two developments in ultrasound have improved the quality of endocardial border definition: harmonic imaging and IV contrast echocardiography.39 Dramatic improvements in image quality have been achieved with the development of harmonic imaging. This technology exploits the formation of ultrasound signals that return to the transducer at a multiple of the transmitted (fundamental) frequency, referred to as the harmonic frequency.40 Signals are received by the ultrasound transducer at twice the transmitted frequency. This “second harmonic imaging” results in images with better contrast between the myocardium and cardiac chambers and improved endocardial definition as compared with fundamental imaging.41–43 Most modern ultrasound devices have harmonic imaging as a standard feature on their system.

In critically ill patients with very poor acoustic windows, endocardial visualization may still be inadequate despite the use of second harmonic imaging.38 In these patients, contrast agents capable of producing LV cavity opacification from a venous injection can be very helpful in delineating the endocardial border (Fig 3). Several contrast agents are currently available that contain albumin microspheres filled with perfluorocarbon gas, allowing for the passage of contrast through the lungs with appearance of contrast in the LV.40 The LV thus becomes opacified by the contrast agent within 1 min of administration, and allows improved endocardial border detection and enhanced Doppler signals.44 Reilly et al45 assessed the benefits of contrast echocardiography for the evaluation of LV function in 70 unselected ICU patients. LV ejection fraction (EF) was obtained in all patients with contrast imaging; however, the EF could not be obtained in 23% of patients with standard imaging and in 13% of patients with harmonic imaging. The EF was read with surety in 56% of patients with standard imaging, in 62% of patients with harmonic imaging, and in 91% of patients with the use of contrast. Yong et al39 extended these observations by comparing the results of harmonic and contrast imaging with an independent standard (ie, TEE) in 32 consecutive critically ill patients who were considered technically very difficult. Estimation of EF was possible in 31% with fundamental imaging, 50% with harmonic imaging, and in 97% with contrast. In critically ill patients with suboptimal TTE image quality, con-
Contrast echocardiography combined with harmonic imaging provides a noninvasive and safe alternative to TEE for determination of regional and global LV function. It is a rapid and simple technique that can be performed at the bedside. This technique should thus be considered in critically ill patients whose TTE are inadequate for evaluation of LV function before the performance of TEE.

**Impact of Bedside Echocardiography in the Critically Ill Patient**

Since its introduction into clinical practice in 1970, the PAC has been the standard hemodynamic monitoring technique for critically ill patients in the ICU, providing the clinician with indexes of cardiovascular function to assist in therapeutic decision making. The PAC can be a very useful diagnostic tool in aiding the management of critically ill patients, but it is clear that its inappropriate use and poor interpretation of the data it provides can lead to excessive morbidity and mortality. Furthermore, contrary to common usage, the PAC is of limited value in the evaluation of global ventricular function and in the assessment of LV preload. Recent studies by Bouchard et al performed in the ICU and Kumar et al in normal subjects have demonstrated significant discrepancies and the limited relationship between hemodynamic values as determined by the PAC and echocardiography. In critically ill patients, echocardiography, particularly TEE, has the ability to clarify diagnosis and define pathophysiologic process in a different and complimentary way to the information obtained from the PAC. Benjamin et al, in a prospective study on performance of limited-scope, goal-directed TEE by intensivists, found that TEE data disagreed with the PAC evaluation of intracardiac volume in 55% of cases and with the PAC assessment of myocardial function in 39% of cases. They also demonstrated that the post-PAC therapeutic recommendations were different from the post-TEE therapeutic recommendations in 58% of patients. In a retrospective analysis of 103 critically ill patients with and without a PAC who underwent TEE, Poelaert et al found that 29 of 66 patients (44%) with a PAC underwent therapy changes after TEE. Furthermore, in 15 of the 37 patients (41%) without a PAC, two-chamber apical view in the same patient after contrast injection. A dramatic improvement in endocardial border definition is noted. Contrast echocardiography combined with harmonic imaging provides a noninvasive and safe alternative to TEE for determination of regional and global LV function.

**Figure 3.** Use of contrast agent to improve endocardial border delineation in a critically ill patient with suboptimal transthoracic image quality. *Top:* A suboptimal transthoracic apical two-chamber view of the LV obtained from a ICU patient with hemodynamic instability receiving mechanical ventilation. The poor endocardial resolution makes regional and global ventricular function very hard to assess. *Bottom:* The same transthoracic two-chamber apical view in the same patient after contrast injection. A dramatic improvement in endocardial border definition is noted. Contrast echocardiography combined with harmonic imaging provides a noninvasive and safe alternative to TEE for determination of regional and global LV function.
TEE led to a change in therapy. These authors concluded that TEE produced a change in therapy in at least one third of their ICU patients independent of the presence of a PAC.59 The major advantage of the PAC vs TEE examination is that the catheter can more easily serve as a continuous monitoring technique to assess the response to a therapeutic intervention.53 However, this potential advantage may provide little benefit in patients in whom the information is misinterpreted or inadequate.

In a prospective study of 115 surgical ICU patients, Bruch et al60 reported that TEE altered treatment in 50 patients (43%). Alterations in medical management included administration of fluid, and the initiation or discontinuation of inotropic agents, anticoagulants, or antibiotics. These findings are similar to those reported in patients in medical or coronary care ICUs.61,62 In a retrospective study done by Cloreavy et al7 on a mixed medical and surgical ICU population, TEE findings led to a significant change in management in 32% of all studies performed. In a prospective study by Heidenreich et al63 of 61 critically ill patients with unexplained hypotension, new diagnoses not observed with TTE were made in 17 patients (28%), leading to surgical intervention in 12 patients (20%).

The available evidence from published studies demonstrates that bedside echocardiography is of considerable benefit in the critically ill ICU patient. The impact on diagnosis and management, particularly with TEE, has been shown to be especially important in patients with unexplained hemodynamic instability and in the postcardiac surgical setting. However, while echocardiography has proven to be a valuable diagnostic tool in the management of critically ill ICU patients, there are no published studies that demonstrate that guiding management via echocardiography improves clinically relevant indexes of patient outcome. Such studies will be important in confirming the role of bedside echo technology in the ICU.

**Other Applications of Bedside Ultrasonography in the ICU**

**Central Line Placement**

Central venous catheterization is frequently performed in critically ill patients. Placement of a central venous catheter is not without risk and can be associated with adverse events that are both hazardous to patients and expensive to treat.56,64,65 Complications have been reported in up to 15 to 20% of cases.56–68 Complications related to central venous line placement are most often mechanical (arterial puncture, local hematoma, hemothorax, pneumothorax), infectious (catheter colonization and related bloodstream infection), and thrombotic.69 Complications are influenced by patient factors (obesity, coagulopathy, previous failed catheterization), site of attempted access, and operator experience.70 Studies71–72 indicate that only 38 to 65% of patients are cannulated on the first attempt using a blind method.

The use of ultrasound guidance during central venous catheterization has been well demonstrated to reduce the risk of complications, most notably for the internal jugular route. It has also been shown to improve the rapidity of catheter placement, decrease the number of attempts before successful placement, and improve the overall rate of successful placement. Ultrasound can be used to simply help localize and define the anatomy of the vein with subsequent placement of central venous catheter by the standard technique. Ultrasound-guided central line placement following failure by the landmark method has had a reported success rate from 33 to 100%.70,74–76 A systematic review76 of the literature reported that placement of central venous catheters under ultrasound guidance significantly decreased placement failure by 64%, decreased complications by 78%, and decreased the need for multiple placement attempts by 40%. Data demonstrating the superiority of the ultrasound guidance technique is consistent for the internal jugular approach but less so for subclavian venous catheterization, which has shown mixed results in clinical trials.76–78

Most large vessels that are catheterized can usually be imaged by ultrasound. Different types of ultrasound modalities can be used to help guiding central vessel cannulation: two-dimensional ultrasound, Doppler transducer, Doppler with the probe in the needle, and fingertip pulse Doppler. With two-dimensional imaging, blood vessels appear black due to near complete transmission of the ultrasound beam.70 Color Doppler will help delineate the flow pattern in the vessel. Doppler-only equipment that provide no images have shown equivocal results in studies77,79 on vascular access. On two-dimensional imaging, arteries are characteristically small, pulsatile, and difficult to compress with the probe.70 Veins are usually larger, nonpulsatile (except in the pres-
ence of severe tricuspid regurgitation), easily compressible, and distended when the patient is placed with his head down or when a Valsalva maneuver is performed. Vessels can be examined in the transverse and longitudinal views. The transverse view permits identification of the vein and artery based on the sonographic characteristics mentioned above and clarifies their relative position to one another. Both the transverse and longitudinal views enable the sonographer to monitor in real-time the passage of the needle through the skin and then the anterior vessel wall, and ensures detailed and accurate control of the needle. During vessel examination, the sonographer should specifically assess the presence and patency of the vein, the distensibility and compressibility of the vein, the relative position of the vein relative to the surrounding arteries, and the presence of a thrombus in the vein. Ultrasonographic identification of certain anatomic characteristics such as small vessel size (<5 mm), intraluminal thrombus, and anterior location of the artery relative to the vein will help the physician identify unfavorable vessel anatomy and so choose another catheterization site. This will clearly help avoiding the high risk of complications that could accompany blind attempts at such suboptimal sites.

Ultrasound-guided central line placement should be considered in patients in whom cannulation may be difficult (Table 2). The benefits demonstrated for ultrasound guidance have been shown across operators with varying levels of experience in central catheter placement and in patients with both low and high risks of potential complications. The technique is easy to learn and can be self-taught with some practical assistance from radiologists or other experienced sonographers.

A recent study by Levin et al showed that use of two-dimensional ultrasound guidance for the insertion of radial artery catheters was easy to use, and increased the rate of success of insertion at first attempt. It was determined to be a useful adjunct to arterial catheter insertion. More studies are needed in the use of ultrasound for cannulation of peripheral arterial conduits.

**Assessment of Pleural Effusions and Intra-abdominal Fluid Collections**

Lung consolidation, atelectasis, and pleural effusions are common in ICU patients and are often present at the same time. Portable, supine, anteroposterior chest radiographs performed in these patients offer limited sensitivity for the diagnosis of pleural effusion. In many instances, neither atelectasis nor infiltration can be differentiated from pleural effusion. Thus, an alternative diagnostic method is needed to provide better information. Decubitus chest radiographs may demonstrate if fluid is free flowing, but they do not localize or characterize the effusion precisely. CT scan of the chest can show the amount and distribution of fluids and is superior to lateral decubitus radiographs. Chest CT can also differentiate fluid from atelectasis and reveal information about the lung parenchyma. However, chest CT requires transport to the radiology suite, which can be hazardous in unstable critically ill patients. Ultrasound examination of the pleural space has proven to be of high value for diagnosis of effusion. Its value to aid in the drainage of pleural effusions with a catheter or for simple thoracentesis is now well recognized. It is especially valuable in guiding drainage of loculated or very small effusions. In the patient receiving mechanical ventilation, it may be hazardous to attempt a blind tap for a suspected effusion, especially if the effusion is small or if the patient is on a high level of positive end-expiratory pressure. Under such circumstances, the potential risk for pneumothorax or other complications is high. Lichtenstein and colleagues evaluated the feasibility and safety of ultrasound-aided thoracentesis in 40 patients receiving mechanical ventilation. No complications occurred in the 45 ultrasound-aided thoracenteses, all performed by intensive care physicians. Similar results have been obtained in a more recent comparable study by Mayo et al. The basic skill required to detect a pleural effusion by ultrasonography can be acquired in a very short period of time.

In most instances, the pleural tap does not have to be done under real-time ultrasound guidance. The patient must be adequately positioned on his back or side. Scanning of the pleural space is then performed with the ultrasound probe. The probe must be oriented upward and downward, laterally and medially, and then anteriorly and posteriorly in order to obtain a complete anatomic assessment of the area. The pleural fluid is hypoechoic and appears

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**Table 2—Criteria for Difficult Central Venous Access**

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<thead>
<tr>
<th>Limited access sites for attempts (e.g., local infection; other catheters present)</th>
<th>Difficult to identify surface landmarks (e.g., local swelling or deformity; severe obesity)</th>
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<tr>
<td>Previous complications (e.g., pneumothorax; arterial puncture)</td>
<td>Previous catheterization difficulties (e.g., multiple sites attempted; failure to gain access; more than three punctures at one site)</td>
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<td>Uncorrected coagulopathy (activated partial thromboplastin time &gt;1.5 times; international normalized ratio &gt;1.8; platelets &lt;50,000 × 10^9/L)</td>
<td>Patient unable to tolerate supine position</td>
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<td>Known underlying vascular anomalies</td>
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black. The surrounding solid structures (soft tissue, diaphragm) and organs (lung, liver, heart, spleen) will be visualized as structures with different degrees of echogenicity around the effusion (Fig 4). The ribs may cause artifactual anechoic images. Once the effusion has been assessed, the feasibility and safety of performing a thoracentesis must be determined. The operator must check for the absence of interposition of lung, heart, liver, or spleen during the respiratory cycle to avoid puncture of such organs that can potentially cause catastrophic complications. Once an optimal and safe position for thoracentesis has been determined, the skin should be marked and disinfected and the patient should remain in the exact same position in which the ultrasound was performed. Optimally, the puncture should be done within seconds to minutes of the marking.

The same diagnostic and therapeutic procedures described above can be applied for intra-abdominal fluid collections. Evaluation for intra-abdominal fluid collection or abscess are restricted to areas that are not impeded by gas-filled structures and include the regions around the liver and gallbladder, spleen, kidneys, and lateral retroperitoneal areas, lateral gutter and pelvis around the uterus and bladder. Fluid that does not change shape with probe pressure or patient positioning most likely represent a loculated collection. A fluid collection with echogenic material and diffuse echoes on ultrasound is suggestive of particulate matter (eg, fibrin or clots) and may represent an exudate or blood collection. As with pleural effusions, intra-abdominal fluid collection can be percutaneously sampled or drained safely at the bedside under real-time ultrasonographic guidance (Fig 5).

**Urinary Bladder Scan**

Bladder-scanning devices are portable units that can provide a measurement of urine volume in the bladder (Fig 6) and thus avoids bladder overdistension and reduce the need for unnecessary catheterization. Studies have shown that frequent catheterization is a major risk factor for urinary tract infections. Moore and Edwards reported a reduction in the incidence of nosocomial urinary tract infections with the use of a portable bladder-scanning device. Bedside ultrasonographic assessment of urinary bladder volume can also be very helpful in the evaluation of oligoanuric patients in whom an obstructive etiology is suspected.

**Focused Assessment for Sonographic Examination of the Trauma Patient**

Since the early 1990s, bedside ultrasound has been used in the United States as an additional diagnostic modality for use in determining the presence of intra-abdominal injury after blunt trauma. It is performed in the trauma bay during the secondary survey (as described in advanced trauma life support) or as part of the primary survey in hemodynamically unstable patients. The focused

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**Figure 4.** Transverse view of a right pleural effusion. A collapsed atelectatic lung is well visualized “floating” in the effusion.

**Figure 5.** Transverse view of a left lower quadrant abdominal collection. Echogenic, particulate material can be seen floating in the collection. Loops of bowel are also well visualized. A 6F catheter was inserted under ultrasound guidance to drain the collection, which was found to be chylous. Fluid collection with echogenic material and diffuse echoes on ultrasound are suggestive of particulate matter (like fibrin or clots) and may represent an exudate or blood collection.
assessment by sonography in trauma examination (FAST) should be done with a specific purpose, usually identification of hemoperitoneum, hemothorax, or cardiac tamponade. Use of the FAST examination has been shown to diminish the need for more invasive diagnostic measures such as diagnostic peritoneal lavage and subsequent exploratory laparotomy. The FAST examination has been shown to be most accurate when performed for evaluation of the hemodynamically unstable patient. Studies have suggested that its use as a screening tool for blunt abdominal injury in hemodynamically stable trauma patient may result in underdiagnosis of intra-abdominal injuries.

**Intra-aortic Balloon Counterpulsation**

Bedside TEE may be of help in different aspects of intra-aortic balloon counterpulsation (IABC) management. Before insertion, it can rule out the presence of significant aortic regurgitation, which would represent a contraindication to IABC use. After insertion, it will be of help in confirming the position of the intra-aortic catheter in the descending thoracic aorta, in assessing the correct functioning of the balloon (visualization of inflation/deflation), and in ruling out the presence of important complications of aortic catheter insertion, most notably aortic dissection. TEE may also be used for monitoring ventricular function while separating the patient from the IABC device.

**Hand-Carried Ultrasound**

The traditional physical examination is often significantly limited in the diagnosis of cardiopulmonary pathology. These diagnostic shortcomings are exaggerated in acutely ill ICU patients. Hand-carried ultrasounds (HCU) are a new generation of portable ultrasound machines that are lightweight (6 to 10 lb), battery powered, and much less expensive ($15,000) than the sophisticated “high-end” machines. Despite the fact that their initial introduction into clinical patient care was met with some criticism, the tremendous potential of HCU to immediately provide diagnostic information at the bedside not assessable by the physical examination alone has been increasingly demonstrated and recognized in the last few years. These devices may facilitate the full clinical potential of ultrasound imaging in the ICU, with true portability, ease of use, and low cost. They are especially powerful when used as an adjunct to the physical examination.

An examination using HCU is usually “directed” toward a specific clinical question and is in general significantly shorter in duration (<6 min in some

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**Figure 6. Urinary bladder.** Top: Suprapubic transverse view of a full urinary bladder. This “square-shape” appearance of the bladder with a concave superior wall is typical of a moderate-full bladder. When overdistended (ie, in the presence of a low urinary tract obstruction), the bladder will be large and adopt a round, globulous shape (not shown). Bottom: Suprapubic transverse view of an empty bladder. When empty, the bladder can become very small and may, not uncommonly, be even difficult to identify.
The disadvantage of such directed examinations with hand-carryed devices is that they are not as comprehensive and can potentially miss some findings compared to traditional echocardiographic examinations. However, the HCU devices should not be compared with the yield or quality of the high-end machines. The HCU should be viewed more as an extension to the physical examination. The accuracy of HCU is not simply one of whether the device produces good images. The factors used to define the accuracy of HCU include the capabilities of the device (imaging modes, accuracy of image) as well as the skill and training of the operator, the circumstances in which the examination is performed, the way it compares with physical examination, and the way it compares with standard echocardiography. Imaging modes and capabilities of currently available HCU machines vary, with color Doppler (true Doppler vs power Doppler), spectral Doppler, harmonics, and capacity to output video and image storage. In general, the accuracy of images created by these devices has shown good agreement when compared to standard echocardiographic machines with respect to two-dimensional findings. Technical limitations of the HCU are mainly due to their small screen (4 to 6 inches) and their limited color Doppler capabilities. Studies have shown HCU sensitivity of two-dimensional imaging for finding abnormal LV function to range from 76 to 96% with lower sensitivity for color Doppler assessment of valvular regurgitation (52 to 96%). Most studies comparing HCU with standard echocardiography were done in the inpatient ward or outpatient practice setting. A recent study done by Gorcsan et al investigated the utility of the HCU when specifically used as an extension of the physical examination on consultative cardiology rounds (n = 235). The HCU demonstrated an excellent close overall agreement (92 to 100%, r = 0.91 to 0.96) for estimation of EF, LV hypertrophy, regional wall motion abnormalities, and pericardial effusion (as assessed by two-dimensional imaging) when compared to an echocardiographic study using a full-size echocardiographic system. The “goal-directed” HCU study was performed in < 10 min and was focused on the above-mentioned diagnoses. HCU data influenced treatment decisions in 149 patients (63%); 50% had a change in medical therapy, and 22% had a change in diagnostic workup. In all, 12 patients (5%) had an immediate change in the decision for cardiac catheterization or pericardiocentesis. The authors of this study concluded that use of “goal-directed HCU has the potential to influence bedside patient treatment decisions and expedite health care.” Concerns have been raised that HCU devices may compare less favorably with standard echocardiography when performed in critically ill patients because of the more frequent occurrence of a limited acoustic window. In a study of 80 critically ill patients that compared HCU vs standard echocardiography, 85% of clinical questions could be addressed by the HCU device. HCU failed to detect a clinically significant finding in 31% of patients; however, the majority of these missed findings were Doppler-based diagnosis (eg, valvular regurgitation). A more recent study by Vignon et al compared the diagnostic capability of HCU and of conventional TTE (used as a “gold standard”) in a population of 106 critically ill patients receiving mechanical ventilation. In this study, the HCU examinations were performed by echocardiography-trained intensivists, and the TTE examinations were reviewed by a cardiologist experienced in echocardiography. They showed that the number of acoustic windows was comparable when using the HCU and conventional TTE in this population of patients. HCU had a lower overall diagnostic capacity than TTE (199 of 251 vs 223 of 251 clinical questions solved, p = 0.005), mainly due to its lack of spectral Doppler capability. However, diagnostic capacity based on two-dimensional imaging was comparable for both approaches (129 of 155 vs 125 of 155 clinical questions solved, p = 0.4). Also, HCU and TTE had a similar therapeutic impact. Results from these studies suggest that the accuracy of HCU with respect to two-dimensional imaging remains very good in the critically ill patient when compared to standard ultrasound machines, but that information derived from HCU color Doppler imaging should be interpreted cautiously in this patient population.

Both the acquisition and interpretation of images are highly dependent on the skill of the operator. Rigorous training is required (minimum of level 2, which consists of having performed > 150 cases and having interpreted > 300) if the goal is the performance and interpretation of a complete echocardiographic study as suggested by the American College of Cardiology and the American Heart Association. However, a lower degree of training is feasible when the goal is to perform a focused examination used as an extension to the physical examination. A focused examination in this context consists mostly in defining ventricular function and diagnosing a pericardial effusion. HCU studies performed by noncardiology medical personnel (medical students, residents, internists) have been demonstrated to be diagnostic in 75 to 90% of patients with a correct interpretation in > 70 to 80% of patients. Training in these studies consisted of 30 min to 40 h of didactic training with some supervised training.
“hands-on” experience.\textsuperscript{133–135} It should be emphasized that the goal of using HCU in the ICU should not be to replace high-end machines but to provide diagnostic data not detected on physical examination. HCU should allow critical care physicians to diagnose certain cardiopulmonary pathologies more rapidly than with standard echocardiography (which are often performed with a variable delay after having been requested). Provided that physicians performing point-of-care examinations with the HCU have adequate training,\textsuperscript{117,129,136} have realistic expectations, and understand the limitations of the device, then the HCU has the potential to create a tremendous advantage for bedside assessment and treatment of the ICU patient.

The value of HCU in the ICU extends beyond the cardiovascular examination in that it allows for the safe performance of bedside procedures that have traditionally been performed blindly. A HCU device will reduce complications associated with central venous cannulation and should be considered the standard of care when performing such hazardous procedures as thoracentesis in patients receiving mechanical ventilation. Equipping critical care physicians with HCUs and training them to perform point-of-care examinations will potentially translate into improved patient care. Although a benefit in terms of clinical outcomes remains to be demonstrated, the utility and impact of HCU at the bedside of critically ill patients can no longer be denied.

\textit{Performance of Bedside Ultrasonography by the Intensivist}

It is usually not feasible to have a cardiologist or sonographer available on immediate call on a 24-h basis to perform bedside ultrasonographic examinations in the ICU. The value of immediate bedside echocardiography for aiding in diagnosis and management of acute hemodynamic disturbances has been well demonstrated in both the ICU and the emergency department.\textsuperscript{137,138} It is recognized that ultrasound technologies are not exclusive to the radiologist or cardiologist. Appropriately trained emergency department physicians, surgeons, anesthesiologists, and intensive care specialists have been using ultrasound devices with great success. Anesthesiologists were instrumental in many of the pioneering studies of TEE in the operating room and ICU.\textsuperscript{14,139–141} Successful performance of bedside echocardiography by noncardiologist intensivists has also been well demonstrated in the literature.\textsuperscript{7,53,123,124,129} Benjamin et al\textsuperscript{53} showed that a limited TEE examination performed and interpreted by intensivists (after training under the supervision of two cardiologists) is feasible and provides rapid, accurate diagnostic information that can have a dramatic impact on the treatment of critically ill patients. The safety and utility of performance of bedside ultrasound by the intensivist for various other purposes in the ICU (central venous cannulation, thoracentesis, paracentesis) have also been well demonstrated.\textsuperscript{71–73,94} With the increasing popularity of HCU devices, there is controversy “in some circles” regarding both the advisability and use of noncomprehensive goal-directed examinations performed by noncardiologists or nonradiologists.\textsuperscript{132} Studies\textsuperscript{119,122–124,129,129} with these portable devices have demonstrated that they can provide important clinical information (see the previous section on HCU) but that even in highly skilled hands they may provide suboptimal imaging or diagnostic capabilities in the ICU setting.\textsuperscript{119} The era of a technology-extended physical examination\textsuperscript{122} appears to have arrived, and there appears to be a role for a user-specific, focused ultrasound examinations.\textsuperscript{132,142} However, adequate training is essential, and this must be individualized and tailored to the specific needs and applications of the user.\textsuperscript{132} With expert back-up, “focused” bedside ultrasonography by intensivists is not only feasible but can be done safely and rapidly and yield information pertinent to the management of critically ill patients. However, inappropriate interpretation or application of data gained by a poorly skilled user may have adverse consequences.\textsuperscript{132} To avoid misusing this technology, adequate training is essential.

General guidelines in training for both TTE and TEE have been developed by the American Society of Echocardiography in association with the American Heart Association and the American College of Cardiology.\textsuperscript{143} Since 1996, the American Society of Anesthesiologists and Society of Cardiovascular Anesthesiologist have developed practice guidelines for perioperative TEE.\textsuperscript{144} The importance of adequate training and subsequent maintenance of competence cannot be overemphasized, as inappropriate use or misapplication could potentially temper the acceptance of bedside ultrasound by the intensivist. Training of intensivists and emergency department physicians in performance of emergency bedside ultrasound should provide rapid answers to clinical questions that may profoundly affect medical and surgical management decisions. Training in echocardiography and general ultrasonography should be incorporated in the critical care fellowship with special emphasis on TEE as part of the training program.\textsuperscript{95,145} It is hoped that critical care and echocardiographic societies will, in the near future, credential such additional training.
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