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Ultrasound in the Surgical Intensive Care Unit

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ABSTRACT: Ultrasonography in the intensive care unit (ICU) has become a valuable tool for expeditiously, safely and effectively diagnosing and treating a myriad of conditions commonly encountered in this setting. Most surgeons are familiar with FAST (**F**ocused **A**ssessment with **S**onography in **T**rauma) and can readily grasp the fundamentals of a limited or directed ultrasonographic exam. Thus, with appropriate training and practice, surgeons can utilize this tool in visualizing, characterizing and treating life-threatening conditions in their role as intensivists in the surgical ICU (SICU). In this review we will discuss the role of ultrasonography in evaluating the acute cardiac status of a patient in the SICU as well as its use in general critical care for assessing the thoracic, abdominal and vascular systems.

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Ultrasonography as a tool for exploring the body has a rich history, as described by Krishnamoorthy et al. [1] and Kendall et al. [2]. It has become a valuable tool in the perioperative evaluation of the cardiothoracic patient and by extension all intensive care unit patients. Simultaneously, surgeons have become familiar with ultrasonography's fundamental characteristics through its use as an examination of the traumatically injured patient, first described as a focused abdominal sonogram for trauma (FAST) by Rozycki and Shackford [3]. Thus, it was only a small leap of imagination to envisage the advantages and benefits of this modality for critically ill and injured patients in the surgical intensive care unit. In this review, we will focus on ultrasonographic applications in the SICU. Applying recent definitions provided by the American College of Chest Physicians and La Société de Réanimation de Langue Française Statement on Competence in Critical Care Ultrasonography [4], we will discuss basic and advanced echocardiography as well as general critical care ultrasonography which can be subdivided into thoracic (pleural and lung), abdominal (to include assessment for intraperitoneal fluid, assessment of the urinary tract, and assessment of the aorta), and vascular ultrasonography (for guidance of vascular access and diagnosis of venous thrombosis).

SICU = surgical intensive care unit

CARDIAC APPLICATIONS

The use of bedside cardiac ultrasonography in the SICU is known to be of benefit in the guidance of care for critically ill and injured patients [5]. Transesophageal echocardiography was considered to be superior in critical care settings in providing optimal sonographic windows and excellent image acquisition. However, with the advent of higher quality portable devices, transthoracic echocardiography has become common practice and is considered to be the primary imaging technique in the ICU setting [6]. Reasons for this shift towards transthoracic ultrasonography include its portability, safety, technologically improved imaging, the brevity of image acquisition, its improved diagnostic accuracy over older technology, and the abridged training required to competently perform bedside studies. Another motivating factor is the ability to continually repeat an ultrasonographic study in the midst of dynamic clinical situations [7]. Thus, TTE has become a superior alternative to TEE, although there is still a role for the latter in distinct clinical situations in the SICU [8]. TTE has an immediate diagnostic impact equivalent to TEE [7] and its therapeutic import is such that the surgical intensivist can use real-time information to cyclically guide management and treatment decisions [9-11].

The intensivist-performed echocardiogram has the advantage of being non-invasive and repeatable and, notably, has immediate bedside application

The aim of a TTE study in the SICU patient is to provide a quick, non-invasive means of determining cardiac function and intraventricular filling and, by inference, intravascular volume. The ideal ICU hemodynamic monitor provides data on preload, contractility and afterload in a dynamic, minimally or non-invasive fashion. Monitoring with central venous or pulmonary artery catheters is known to have no correlation between pressure values obtained via these monitors and intravascular volume or ventricular filling status [12-14]. Moreover, four studies have demonstrated no ben-

TTE = transthoracic echocardiography
TEE = transesophageal echocardiography

efit of pulmonary artery catheters vis-à-vis patient outcomes [15-18]. TEE preload measurements have been shown to be "well validated and more accurate than data obtained from pulmonary artery catheters" [19]. By extension, TTE should reasonably be able to garner the same information. However, mixed results have been noted when using echocardiography to predict fluid responsiveness [12] and to date there are no studies documenting a positive patient-oriented outcome with this technology.

There are multiple resources for training in basic echocardiography, including courses offered by the American College of Surgeons, the Society of Critical Care Medicine, the World Interactive Network Focused on Critical UltraSound (WINFOCUS), and Imaging, a program provided by intensive cardiac care units, which consists of a multimedia curriculum titled FOcused Cardiac Ultrasound Study (FOCUS). Guidelines proposed by the American College of Chest Physicians and the La Société de Réanimation de Langue Française Statement on competence in critical care ultrasonography [4] recommend two levels of competence.

Thoracic ultrasonography may be useful in uncovering the etiology of acute hypoxemia in the critically ill or injured patient

The first level of competence, "basic," is considered a bedside TTE defined in the literature as a "limited ultrasound," "goal-directed ultrasound," "point-of-care focused ultrasound" [20], or intensivist bedside ultrasound (INBU) [21]. The goal at this basic level is threefold: a) to acquire the ability to qualitatively assess left and right ventricular size and function, b) to measure the inferior vena cava diameter while accounting for respiratory variation, and c) to qualitatively assess for severe valvular regurgitation. Competences in image interpretation as well as recognition of clinical syndromes are detailed but a minimum number of studies necessary to achieve competency is not defined in this position paper. Variations upon the "basic" study include extension of the examination to visualize pleura on both sides, as in a Focus Assessed Transthoracic Echocardiogram (FATE) [22] or stroke volume measurement using the fractional shortening technique to compute the cardiac index as in the Bedside Echocardiographic Assessment in Trauma/Critical Care (BEAT) [23]. These "basic" studies are not meant to be comprehensive cardiac evaluations but are weighted towards specificity over sensitivity [24] and qualitative over quantitative information in ascertaining whether certain clinical conditions are present.

The second level of competence, "advanced," is a "comprehensive hemodynamic evaluation and monitoring" [4] that addresses specific clinical entities such as infectious endocarditis, right-to-left shunts, pulmonary embolus and complications of acute myocardial infarction that might require more subtle and complex cardiac chamber and valvular pattern and flow recognition. To achieve this level, an individual must also be facile in the use of TEE as many of these disease processes are best imaged in this mode.

Table 1. Bedside echocardiographic assessment: the BEAT exam

Meaning of BEAT acronym	Goal	View	Task
Beat (cardiac index)	Cardiac function	Parasternal long	Stroke volume
Effusion	Pericardial effusion	Parasternal long	Subjective assessment
Area (ventricular size and function)	Right and left ventricle	Parasternal short Apical 4 chamber	Subjective assessment
Tank (preload)	Volume status	M mode subcostal	Inferior vena cava measurement

Can "basic" TTE be learned and performed by surgeon-intensivists with good quality image acquisition? Several studies have demonstrated that after a brief educational intervention non-cardiologists are able to perform limited transthoracic examinations and correctly interpret studies most of the time [25,26]. In answering the question whether quality clinical images can be obtained by surgeon-intensivists, one can look at the study by Gunst and colleagues [23] in which FAST-trained surgeons received a 2 day "Focused Cardiac Ultrasound at Bedside Seminar" and then went on to prove their competence on normal volunteers. Utilizing the framework of a BEAT examination [Table 1], 59% of the cardiac exams were rated as being of good quality.

Do bedside ultrasonographic studies make any difference to patient care? In a study by Orme and associates [10], there was a change in patient management in 48.6% of all TTEs (187 studies). A study by Stanko and colleagues [11] found a change in diagnosis in 29% and a change in management in 41% of the studies performed (135 TTEs done in 126 patients). Although a change in diagnosis or management can frequently be anticipated using this modality, no study has demonstrated a difference in patient outcomes.

THORACIC APPLICATIONS

Due to the physics of ultrasound, air in the inflated lung normally prevents visualization of its detailed structure. Nevertheless, several pathological processes in the thoracic cavity can be identified easily by bedside ultrasound.

Pneumothorax and pleural effusion (hemothorax) are common pulmonary pathologies seen in the ICU setting. A chest radiograph in critically ill patients may have insufficient sensitivity to detect both of these etiologies of respiratory failure in the SICU [27]. Though a computed tomographic scan should offer a more accurate diagnosis, it is often not possible for critically ill patients to travel to the radiology suite. A pneumothorax can be life threatening in SICU patients. Although a detailed physical

FAST = focused assessment with sonography in trauma
BEAT = bedside echocardiographic assessment in trauma/critical care

examination is the first step to establish the diagnosis, thoracic ultrasound demonstrates fairly high sensitivity and specificity compared with chest radiography [27,28]. The ultrasound findings of a pneumothorax can be characterized by loss of artifacts seen in normal lung, namely lung sliding and the presence of B-lines (comet-tail sign). Lung sliding is the movement across the parietal and visceral pleura surfaces seen in the intercostal spaces. B-lines (comet tails) are vertical hyperechoic artifact lines originating from the horizontal pleural line under sonography. Both artifacts are detected with low and high frequency transducer probes.

Pleural effusions and hemothoraces are seen as hypo- or anechoic areas in the posterior and inferior thoracic cavity of a supine patient. Although computed tomography scan is more sensitive for detecting hemothoraces and pleural effusions, pleural ultrasonography can be helpful in detecting these abnormalities in the pleural space. In the setting of trauma, Sisley and co-workers [29] first described transthoracic ultrasonography as an extension of the sonographic evaluation of the trauma patient (FAST). In their examination of both the right and left supradiaphragmatic regions for evidence of a hemothorax, they noted a 97.5% sensitivity and 99.7% specificity, similar to the sensitivity and specificity of a chest X-ray. Rozycki and colleagues [30] reported on the efficacy of bedside ultrasound for detecting pleural effusions in the surgical ICU. Their sensitivity for fluid in the thoracic cavity was 83.6% and specificity was 100%. Once a patient is found to have a pleural effusion, ultrasound-guided thoracentesis is regarded as another utility for the bedside ultrasound [31].

Ultrasound-guided central venous access is the standard of care in all settings, including the SICU, and has been proven to increase the chances for successful placement and reduce the risk of complications

Finally, lung ultrasonography can be used to detect pulmonary edema, pulmonary embolism, pneumonia, chronic obstructive pulmonary disease or asthma, or pneumothoraces utilizing the Bedside Lung Ultrasound in Emergency (BLUE) protocol with 90.5% accuracy in disease identification [32].

ABDOMINAL APPLICATIONS

Deterioration of a patient's condition can often be attributed to intraabdominal pathology in the SICU. Ultrasound can identify the abdominal organ-related etiologies in a timely manner at the bedside without the need for transport to the radiology suite. However, abdominal ultrasound in the ICU setting has several limitations. Tissue edema or obesity may prevent acquisition of a clear view of abdominal organs. Surgical wounds, tubes or drains also make the ultrasound examination more difficult. Patients with an open abdomen are technically not amenable for ultrasound examination. Other limiting factors include rib shadowing, bowel gas, and uncooperativeness of patients (positioning, breathing).

Table 2. Problem-focused abdominal ultrasound in surgical intensive care unit

Goal	Task
Identify fluid	Amount, location, loculation
Characterize mass lesion	Locate fascia
Leukocytosis, abdominal pain	View gallbladder, appendix, bowel, aorta
Jaundice	View gallbladder, common bile duct, intrahepatic biliary ducts, presence of stone
Decreased urine output	View bladder, presence of hydronephrosis
Transplant evaluation	Arterial/venous blood flow, organ size, tenderness

Therefore, the ultrasound technique for critical ill patients should be different from a routine screening examination. A problem-oriented approach is key to the efficient utilization of abdominal ultrasound in the ICU setting [Table 2].

Application of the FAST examination for detecting free fluid within the abdomen dramatically changed the approach to the trauma patient [33]. This technique surveys four points (epigastrium, right upper quadrant, left upper quadrant, and pelvic space) for pericardial and peritoneal fluid and in a trauma cohort was able to identify as little as 100 ml of fluid with 88% sensitivity, 99% specificity and 97% accuracy [34].

Pneumoperitoneum can signal a ruptured hollow viscus. Unreliable physical examinations in sedated patients on mechanical ventilation can often delay the diagnosis and appropriate intervention. Even portable radiography, easily performed at bedside, is not always accurate [35]. Although CT scanning is more sensitive to detect pneumoperitoneum, SICU patients are not always transportable to the scanner. A recent article by Moriwaki et al. [36] demonstrated that surgeon-performed ultrasound achieved 85.7% sensitivity for intraperitoneal free air in blunt abdominal trauma and 85.0% in acute abdominal pain. The ultrasound technique for pneumoperitoneum uses the same principle as that for diagnosing a pneumothorax. In a supine patient, free air can be detected on the surface of the liver. A low frequency transducer is placed in the right upper quadrant and high echoic reverberation is seen as a positive finding of pneumoperitoneum.

Liver abscess, acute cholecystitis and acute cholangitis should be kept in mind as an origin of fever in the ICU setting. Bedside ultrasound is considered a first-choice modality for the workup of jaundice. Factors of interest when performing liver ultrasound include abscesses, mass lesions, dilatation of intrahepatic duct, or portal venous gas. A liver abscess can be drained at bedside by ultrasound guidance. Biliary tract ultrasound in the ICU should focus on searching for cholelithiasis/

sludge, features of cholecystitis, choledocholithiasis and dilatation of the common bile duct. Although wall thickness of the gallbladder (> 3 mm) is a finding suggestive of acute cholecystitis, a variety of other conditions may also manifest this finding. Percutaneous cholecystostomy may be required to definitively establish the diagnosis and treatment of acute cholecystitis in high risk patients. Again, bedside ultrasound-guided drainage can be safely performed by the intensivist [37].

Acute kidney injury is a serious complication often encountered in critically ill patients. Ruling out post-renal etiology is the first step in its workup. The level of obstruction can be estimated based on the findings in the bladder, ureter and kidney. A distended bladder implies an obstructive process in the urethra or urethral catheter. Hydronephrosis without bladder distension suggests an obstructive lesion in the ureter (stone, tumor, fibrosis).

VASCULAR APPLICATIONS

Vascular ultrasonography for central venous line placement has been shown to significantly increase the overall chances for successful placement on the first attempt and to reduce the rate of complications [38]. The data were most compelling for internal jugular vein central venous line placement over subclavian vein cannulations. Thus, this technique has been recommended in the United States by the Agency for Healthcare Research and Quality (2001) [39] for all central venous line insertions and in the United Kingdom by the National Institute for Clinical Excellence (NICE) [40] for internal jugular venous cannulations. Because of demonstrable clinical success and the aforementioned evidence-based reports, ultrasonography for obtaining vascular access in the axillary, brachial, femoral and other peripheral veins (as well as for obtaining arterial access) has become the norm. Vascular ultrasonography has also had a long history of use for the identification of venous thrombosis within the upper and lower extremity veins.

The expansion of ultrasonography in the ICU is due to improved training, improved technology and improved imagination. Now that it is ubiquitous in trauma bays and becoming so in the intensive care units internationally, we as critical care specialists and surgeons need to continue to expand upon its uses and truly utilize ultrasonography as an extension of our physical examination.

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References

1. Krishnamoorthy VK, Sengupta PP, Gentile F, Khandheria BK. History of echocardiography and its future applications in medicine. *Crit Care Med* 2007; 35 (8 Suppl): S309-13.
2. Kendall JL, Hoffenberg SR, Smith RS. History of emergency and critical care ultrasound: the evolution of a new imaging paradigm. *Crit Care Med* 2007; 35 (5 Suppl): S126-30.
3. Rozycki GS, Shackford SR. Ultrasound, what every trauma surgeon should know. *J Trauma* 1996; 40 (1): 1-4.
4. Mayo PH, Beaulieu Y, Doelken P, et al. American College of Chest Physicians/ La Societe de Reanimation de Langue Francaise statement on competence in critical care ultrasonography. *Chest* 2009; 135 (4): 1050-60.
5. Beaulieu Y, Marik PE. Bedside ultrasonography in the ICU: Part 1. *Chest* 2005; 128 (2): 881-95.
6. Salem R, Vallee F, Rusca M, Mebazaa A. Hemodynamic monitoring by echocardiography in the ICU: the role of the new echo techniques. *Curr Opin Crit Care* 2008; 14 (5): 561-8.
7. Joseph MX, Disney PJ, Da Costa R, Hutchison SJ. Transthoracic echocardiography to identify or exclude cardiac cause of shock. *Chest* 2004; 126 (5): 1592-7.
8. Huttemann E. Transoesophageal echocardiography in critical care. *Minerva Anestesiol* 2006; 72 (11): 891-913.
9. Jones AE, Tayal VS, Sullivan DM, Kline JA. Randomized, controlled trial of immediate versus delayed goal-directed ultrasound to identify the cause of nontraumatic hypotension in emergency department patients. *Crit Care Med* 2004; 32 (8): 1703-8.
10. Orme RM, Oram MP, McKinstry CE. Impact of echocardiography on patient management in the intensive care unit: an audit of district general hospital practice. *Br J Anaesth* 2009; 102 (3): 340-4.
11. Stanko LK, Jacobsohn E, Tam JW, De Wet CJ, Avidan M. Transthoracic echocardiography: impact on diagnosis and management in tertiary care intensive care units. *Anaesth Intensive Care* 2005; 33 (4): 492-6.
12. Bendjelid K, Romand JA. Fluid responsiveness in mechanically ventilated patients: a review of indices used in intensive care. *Intensive Care Med* 2003; 29 (3): 352-60.
13. Kumar A, Anel R, Bunnell E, et al. Pulmonary artery occlusion pressure and central venous pressure fail to predict ventricular filling volume, cardiac performance, or the response to volume infusion in normal subjects. *Crit Care Med* 2004; 32 (3): 691-9.
14. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. *Chest* 2008; 134 (1): 172-8.
15. Sandham JD, Hull RD, Brant RF, et al. A randomized, controlled trial of the use of pulmonary-artery catheters in high-risk surgical patients. *N Engl J Med* 2003; 348 (1): 5-14.
16. Richard C, Warszawski J, Anguel N, et al. Early use of the pulmonary artery catheter and outcomes in patients with shock and acute respiratory distress syndrome: a randomized controlled trial. *JAMA* 2003; 290 (20): 2713-20.
17. Harvey S, Harrison DA, Singer M, et al. Assessment of the clinical effectiveness of pulmonary artery catheters in management of patients in intensive care (PAC-Man): a randomised controlled trial. *Lancet* 2005; 366 (9484): 472-7.
18. Wheeler AP, Bernard GR, Thompson BT, et al. Pulmonary-artery versus central venous catheter to guide treatment of acute lung injury. *N Engl J Med* 2006; 354 (21): 2213-24.
19. Swenson JD, Bull D, Stringham J. Subjective assessment of left ventricular preload using transesophageal echocardiography: corresponding pulmonary artery occlusion pressures. *J Cardiothorac Vasc Anesth* 2001; 15 (5): 580-3.
20. Breitkreutz R, Walcher F, Seeger FH. Focused echocardiographic evaluation in resuscitation management: concept of an advanced life support-conformed algorithm. *Crit Care Med* 2007; 35 (5 Suppl): S150-61.
21. Carr BG, Dean AJ, Everett WW, et al. Intensivist bedside ultrasound (INBU) for volume assessment in the intensive care unit: a pilot study. *J Trauma* 2007; 63 (3): 495-500.
22. Jensen MB, Sloth E, Larsen KM, Schmidt MB. Transthoracic echocardiography for cardiopulmonary monitoring in intensive care. *Eur J Anaesthesiol* 2004; 21 (9): 700-7.
23. Gunst M, Sperry J, Ghaemmaghami V, O'Keeffe T, Friese R, Frankel H. Bedside echocardiographic assessment for trauma/critical care: the BEAT exam. *J Am Coll Surg* 2008; 207 (3): e1-3.

24. Beaulieu Y, Marik PE. Bedside ultrasonography in the ICU: Part 2. *Chest* 2005; 128 (3): 1766-81.
25. Vignon P, Dugard A, Abraham J, et al. Focused training for goal-oriented hand-held echocardiography performed by noncardiologist residents in the intensive care unit. *Intensive Care Med* 2007; 33 (10): 1795-9.
26. Melamed R, Sprenkle MD, Ulstad VK, Herzog CA, Leatherman JW. Assessment of left ventricular function by intensivists using hand-held echocardiography. *Chest* 2009; 135 (6): 1416-20.
27. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Acad Emerg Med* 2005; 12: 844-9.
28. Soldati G, Testa A, Sher S, et al. Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. *Chest* 2008; 133: 204-11.
29. Sisley AC, Rozycki GS, Ballard RB, et al. Rapid detection of traumatic effusion using surgeon-performed ultrasonography. *J Trauma* 1998; 44: 291-6.
30. Rozycki GS, Pennington SD, Feliciano DV. Surgeon-performed ultrasound in the critical care setting: its use as an extension of the physical examination to detect pleural effusion. *J Trauma* 2001; 50: 636-42.
31. Mayo PH, Doelken P. Pleural ultrasonography. *Clin Chest Med* 2006; 27: 215-27.
32. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008; 134: 117-25.
33. Rozycki GS, Ballard RB, Feliciano DV, Schmidt JA, Pennington SD. Surgeon-performed ultrasound for the assessment of truncal injuries: lessons learned from 1540 patients. *Ann Surg* 1998; 228: 557-67.
34. McKenney MG, Martin L, Lentz K, et al. 1,000 consecutive ultrasounds for blunt abdominal trauma. *J Trauma* 1996; 40: 607-10.
35. Chen SC, Yen ZS, Wang HP, Lin FY, Hsu CY, Chen WJ. Ultrasonography is superior to plain radiography in the diagnosis of pneumoperitoneum. *Br J Surg* 2002; 8: 351-4.
36. Moriwaki Y, Sugiyama M, Toyoda H, et al. Ultrasonography for the diagnosis of intraperitoneal free air in chest-abdominal-pelvic blunt trauma and critical acute abdominal pain. *Arch Surg* 2009; 144: 137-41.
37. Nicolaou S, Talsky A, Khashoggi K, Venu V. Ultrasound-guided interventional radiology in critical care. *Crit Care Med* 2007; 35 (5 Suppl): S186-97.
38. Hind D, Calvert N, McWilliams R, et al. Ultrasonic locating devices for central venous cannulation: meta-analysis. *BMJ* 2003; 327: 361.
39. Shojania KG, Duncan BW, McDonald KM, et al. Making health care safer: a critical analysis of patient safety practice. *Evid Rep Technol Assess* 2001; 43: 1-668.
40. National Institute for Clinical Excellence. Guideline on the use of ultrasound location devices for placing central venous catheters. (NICE Technology appraisal guidance, No. 49) London: NICE, 2002.