Ultrasonography 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 (Focused Assessment with Sonography in Trauma) 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.

KEYWORDS: ultrasound, intensive care unit, echocardiography, limited exam, critical care

Ultrasoundography 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 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.

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 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-
benefit 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 care card 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.

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.

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

<table>
<thead>
<tr>
<th>Table 1. Bedside echocardiographic assessment: the BEAT exam</th>
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<tr>
<td>Meaning of BEAT acronym</td>
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<tr>
<td>Beat (cardiac index)</td>
</tr>
<tr>
<td>Effusion</td>
</tr>
<tr>
<td>Area (ventricular size and function)</td>
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<tr>
<td>Tank (preload)</td>
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**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

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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].

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].

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

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

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 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.

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References

**Capsule**

**DNA released from dying host cells mediates aluminum adjuvant activity**

Aluminum-based adjuvants (aluminum salts or alum) are widely used in human vaccination, although their mechanisms of action are poorly understood. Marichal and co-workers report that, in mice, alum causes cell death and the subsequent release of host cell DNA, which acts as a potent endogenous immunostimulatory signal-mediating alum adjuvant activity. Furthermore, the authors propose that host DNA signaling differentially regulates immunoglobulin E (IgE) and IgG1 production after alum-adjutanted immunization. They suggest that, on the one hand, host DNA induces primary B cell responses, including IgG1 production, through interferon response factor 3 (Irf3)-independent mechanisms. On the other hand, host DNA also stimulates ‘canonical’ T helper type 2 (Th2) responses, associated with IgE isotype switching and peripheral effector responses, through Irf3-dependent mechanisms. The finding that host DNA released from dying cells acts as a damage-associated molecular pattern that mediates alum adjuvant activity may increase our understanding of the mechanisms of action of current vaccines and help in the design of new adjuvants.

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Eiltan Israeli

**Capsule**

**Alzheimer’s therapy by transport of the therapeutic antibody across the blood-brain barrier**

With the continued increase in human lifespan, the incidence of Alzheimer’s disease is rising, prompting a need for innovative therapies that can slow or stop the progression of this devastating condition. Since the discovery of the β-amyloid precursor protein site cleaving enzyme (BACE), which initiates the production of the Alzheimer’s associated peptide Aβ, it has been one of the most intensely investigated Alzheimer’s disease targets. Watts et al. have used a bi-specific antibody approach to target this enzyme, which allows transport of the therapeutic antibody across the blood-brain barrier (BBB). The bi-specific antibody reduced the levels of brain Aβ more effectively than a monospecific antibody to BACE1, and this targeting approach could potentially even be applied to treat other neurological diseases.

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Eiltan Israeli

“The willow which bends to the tempest, often escapes better than the oak which resists it; and so in great calamities, it sometimes happens that light and frivolous spirits recover their elasticity and presence of mind sooner than those of a loftier character”

Walter Scott (1771-1832), British novelist and poet