EMERGING TECHNOLOGY REVIEW

Gerard R. Manecke, Jr, MD
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Perioperative Anesthesiology UltraSonographic Evaluation (PAUSE): A Guided Approach to Perioperative Bedside Ultrasound

Adam C. Adler, MD, MS,* William J. Greeley, MD, MBA,** Frederick Conlin, MD, ASCEXAM,‡§ and Jeffrey M. Feldman, MD††

BEDSIDE, OR POINT OF CARE, ultrasonography is emerging as a tool for real-time diagnostic assessment in addition to standard physical examination in the emergency department, intensive care unit, and now in the perioperative period as ultrasound didactics are being incorporated into residency training programs. Even though anesthesiologists have embraced the use of bedside ultrasound as a procedural tool, diagnostic use of this technology is underutilized, with the exception of transesophageal echocardiography (TEE) and lung ultrasonography, have been previously unrecognized cardiac tamponade preoperatively leading to a change in management for 82% of cases. In the Cowie cohort, use of TTE led to escalation or de-escalation of invasive monitoring strategies, procedure location changes or cancellations, fluid boluses or restrictions, or alteration in anesthetic management, and 20% of patients were referred for formal cardiology evaluation. Using bedside TTE in 99 patients with known or suspected cardiac disease, Canty et al found a significant number of patients with aortic stenosis, cardiac failure, tamponade, or significant intravascular volume depletion, leading to a change in management in 36% of patients. Applying focused cardiac ultrasound, Gerlach et al identified a previously unrecognized cardiac tamponade preoperatively while attempting to assess the patient’s overall cardiac function.

This article reviews some clinical scenarios in which point-of-care ultrasonography might prove efficacious in the perioperative setting. The goal is to provide a structured approach to using bedside ultrasound as a physical examination adjunct and diagnostic tool that can be learned and performed by the general anesthesiologist. The Perioperative Anesthesiology UltraSonographic Evaluation (PAUSE) approach is a tool for the anesthesiologist to pause at various times during perioperative management and use bedside ultrasonography to assess the patient, extending the information provided by physical examination or vital sign monitoring. This approach to the use of ultrasound is described along with recommendations for how providers, new to the use of ultrasound for diagnostic imaging, can learn and properly apply these skills.

From the *Department of Anesthesiology and Critical Care Medicine, Division of Cardiothoracic Anesthesiology; The Children’s Hospital of Philadelphia, Philadelphia, PA; †The University of Pennsylvania Perelman School of Medicine, Philadelphia, PA; ‡Department of Anesthesiology, Baystate Medical Center, Springfield, MA; and §Tufts University School of Medicine, Boston, MA.

Address reprint requests to Adam C. Adler, MD, MS, Department of Anesthesiology and Critical Care Medicine, Division of Cardiothoracic Anesthesiology, The Children’s Hospital of Philadelphia, The University of Pennsylvania Perelman School of Medicine, 34th Street and Civic Center Boulevard, Philadelphia PA 19104. E-mail: adamatadler@gmail.com

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The success of modern medicine at managing chronic disease and increasing longevity has created a challenging patient population for the anesthesiologist. Not only are acuity and disease burden increasing, but there may be little time before a scheduled procedure to safely risk stratify patients and balance safe anesthetic care with the need to delay or cancel a procedure to obtain additional information. Medical history alone may be unreliable, unattainable, or clouded by comorbidities such as limited exercise tolerance due to joint disease or obesity. Consider the following scenario:

You are on call and evaluating an 85-year-old female for repair of a hip fracture after an unwitnessed fall at home. She is confused and mildly hypotensive with parched mucous membranes, and a murmur is heard over the right parasternal boarder. Medical records are not immediately available. How can bedside ultrasound be of assistance in the preoperative clinical decision-making process?

Few would argue that this patient requires careful assessment of volume status, underlying ventricular function, and the potential for a significant cardiac valve abnormality before she enters the operating room. Fig 1 suggests a basic approach for using ultrasonography to expeditiously evaluate items of cardiovascular interest in the preoperative setting. There often is a great deal of information available using the parasternal short- and long-axis views. Although complementary views

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**Fig 1.** Perioperative Anesthesia UltraSonographic Evaluation (PAUSE) approach for preoperative bedside ultrasound patient evaluation. LV, left ventricle; IVC, inferior vena cava; M-mode, motion mode; PLR, passive leg raise.
may be needed to confirm a diagnosis, the parasternal views are a good place to start scanning and may be the most accessible during procedures for comparison with baseline preoperative views.

**Volume Status**

Patients with prolonged fasting times, intestinal obstructions, and gastrointestinal illnesses, and patients whose conditions are stable, but who are only partially resuscitated following trauma, benefit from preoperative assessment of intravascular volume status before induction of general anesthesia.

Examination of the left ventricle (LV) via the parasternal long- and short-axis views provides a gross assessment of volume status and overall ventricular function. A highly collapsed central cavity (end-systolic cavity obliteration) is suggestive of significant intravascular volume depletion. Fluid administration guided by repeated assessment of LV cavity size can be useful to reduce the risk of hypotension after induction of anesthesia.

Assessment of the inferior vena cava (IVC) can be performed to evaluate for respiratory variation and collapsibility. Preoperative evaluation of the IVC can serve as a baseline for comparison and may be examined serially in the preoperative area or in the post-anesthesia care unit (PACU) for assessment of response to fluid administration. During spontaneous ventilation, IVC measurements of <2 cm, with an inspiratory collapse of >50%, correlate with intravascular volume depletion (low right atrial [RA] pressure, central venous pressure [CVP] <10 cm H₂O); whereas measurements >2 cm with an inspiratory collapse of <50% suggest vascular fullness (CVP >10 cm H₂O). During positive-pressure ventilation, these relationships are reversed because the IVC tends to be distended throughout the respiratory cycle. However, the IVC distensibility index may be monitored serially in ventilated patients as discussed later in this article.

**Basic Cardiac Function**

Patients who present for surgery frequently report limited or no exercise tolerance and a history of heart “issues” or have not undergone further cardiac evaluation. Parasternal view of the LV in the short-axis should, in most circumstances, be sufficient to identify regions of the LV that are severely hypokinetic or completely akinetic. In the same view, the practitioner can make a crude assessment of LV ejection fraction to identify patients with extremely poor ventricular function and decide whether further evaluation by a cardiologist, referral to a cardiac anesthesiologist, or case cancellation is warranted. The ability to assess and make informed decisions on overall function requires some training in bedside imaging as discussed later in this article.

**The Precarious Murmur**

The perioperative murmur appears in a variety of presentations. Patients often reveal a history of a heart murmur, or the astute physician or nurse may auscultate a murmur in the preoperative area on the morning of surgery. Clinically significant murmurs often are underestimated with auscultation alone. Risk factors for intraoperative mortality, such as aortic stenosis, are common in the elderly and especially the hip fracture population. Often, these operations are performed at times of the day not amenable to formal echocardiographic evaluation or cardiology consultation. Rapidly obtainable cardiac ultrasound views allow the anesthesiologist to correlate a murmur with the potential for a severely stenotic or regurgitant lesion. The parasternal long-axis view provides a look at the aortic valve in the long axis. The apical 4-chamber or subcostal views allow the tricuspid and mitral valves to be examined. Application of color-flow Doppler is important to identify severe abnormalities of the valves (as discussed below).

Preoperative bedside imaging may provide the anesthesiologist additional information in deciding the risk-benefit ratio of proceeding with a case versus cancellation to afford further cardiac evaluation and medical optimization. Ultrasound should be used when the potential for a serious valve abnormality is uncertain. Ultrasound assessment of valvular function is an advanced skill, and any indication of serious stenosis or insufficiency should prompt further workup if appropriate. There will be times when the novice practitioner will place the probe and feel comfortable that a severe pathologic condition is not present and proceed to surgery. However, if there is a concern based on the novice clinician’s imaging, additional workup is warranted. If the novice clinician has some level of training and is comfortable that no “severe” pathologic condition exists, then proceeding to surgery is acceptable; however, the decision whether to proceed with a particular case should be based on the providers’ degree of comfort with the pathologic condition identified and support resources on hand.

In the aforementioned case scenario of the 85-year-old woman, bedside ultrasound may identify a very mild aortic stenosis with no appreciable stenotic jets, but also may reveal major volume depletion with end-systolic cavity obliteration, IVC collapsibility, and a hyperdynamic ventricle. In such a case, careful volume administration before induction of anesthesia may be warranted. Conversely, the provider may identify a miniscule aortic valve orifice and massive LV hypertrophy combined with volume depletion and may alter case management, such as placing a pre-induction arterial catheter or delaying the case for further optimization, cardiology evaluation, or transfer to a tertiary center if appropriate.

**INTRAOPERATIVE EVALUATION USING ULTRASONOGRAPHY**

Preoperative assessment using ultrasound can generate views that can be used for comparison throughout the procedure, especially parasternal views that are likely to be accessible during the procedure. Managing refractory hemodynamic instability (ie, low or borderline blood pressure that is not responsive to expected interventions of fluid management) and/or adjustment of anesthetic depth can be particularly challenging, especially when pressor agents are unexpectedly required to support blood pressure or are simply ineffective. Consider the following scenario:

*You are the anesthesia provider for a 62-year-old male undergoing an emergency exploratory laparotomy for bowel obstruction who was supposedly otherwise healthy. His condition remains hypotensive despite reasonable...*
anesthetic depth and considerable volume resuscitation. Pressor agents are being considered. How can bedside ultrasound be of assistance in the intraoperative clinical decision-making process?

This ultrasonographic assessment guide was developed to allow for rapid diagnosis with the most appropriate views of the most commonly encountered etiologies of intraoperative hemodynamic instability (Fig 2). This approach using bedside
ultrasound may help the anesthesiologist identify the specific etiology of hemodynamic instability, thereby avoiding delays in treatment. The authors recommend starting with the parasternal long-axis view, a good reference point for ultrasound orientation. With rotation of the probe 90 degrees, the parasternal short-axis view should follow to assess volume status and LV function. Generally, either the apical or subcostal view, if accessible, should be obtained next to identify any atrioventricular valve issues and help confirm the images obtained with the parasternal views. The remainder of the examination should progress based on clinical suspicion (ie, suspicion of pneumothorax [central catheter/supraclavicular block] or assessment of preload [hemorrhage] or pulmonary embolism [venous stasis]) and include IVC or parasternal pulmonary artery bifurcation views as applicable.

The IVC can be evaluated immediately after induction of anesthesia to allow for baseline measurements in cases in which the surgical exposure will limit access. The IVC distensibility index has been validated in mechanically ventilated patients. Although the IVC diameter is affected by ventilatory parameters, calculation of the index accounts for these changes. The IVC view with or without M-mode is used to obtain cyclic changes in IVC diameter. These changes have been shown to correlate with volume status. If the maximum inspiratory and minimum expiratory diameters are obtained during positive-pressure tidal volume ventilation (8 mL/kg), it is possible to assess volume status by the distensibility index.

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\text{Distensibility Index } = \left( \frac{\text{IVCmax} - \text{IVCmin}}{\text{IVCmax}} \right) \times 100 = DI(\%)
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The IVC diameter can be measured with a caliper on the ultrasound machine (Supplementary Material Figs S5A and B). During spontaneous ventilation, measurements of <2 cm, with an inspiratory collapse of >50%, correlate with intravascular volume depletion (low RA pressure, CVP <10 cm H₂O), whereas measurements >2 cm, with an inspiratory collapse of <50%, suggest vascular fullness; these measurements are indications of adequate volume or inability of the heart to accept volume, respectively. As noted previously, during positive-pressure ventilation, these relationships are reversed because the IVC tends to be distended throughout the respiratory cycle, and the distensibility index may be used to identify patients who may respond to volume administration. Distensibility indices >18% identified fluid-responsive patients compared with non-responders, with both a sensitivity and specificity of 90%. In the intraoperative ultrasonography case scenario, bedside ultrasound may, for example, identify a dilated heart from longstanding undiagnosed ischemic heart disease or a large pulmonary embolism or pericardial effusion as sequelae from the malignant process just found in the bowel.

POSTOPERATIVE EVALUATION USING ULTRASONOGRAPHY

Hypotension can be a common reason for being called to the PACU to evaluate a patient. Consider the following scenario:

You are called to evaluate a 72-year-old, obese female who underwent general anesthesia in the PACU after knee replacement. Her history includes diabetes, hypertension, and coronary artery disease. She has been immobile due to severe knee osteoarthritis. Her condition remains hypotensive despite the administration of 5 L of crystalloid in the operating room. How can bedside ultrasound be of assistance in the postoperative clinical decision-making process?

In contrast with the classic determination of shock states, the postoperative and postanesthetized patient has a specific differential for post-operative hypotension.

Ultrasound evaluation of postoperative hemodynamic instability should exclude major cardiac causes. Hypovolemia is the most common cause of postoperative low blood pressure, but empiric fluid administration can cause complications, especially in a patient who already has received significant parenteral fluid therapy. The parasternal long-axis view can provide information regarding LV function and volume status and is a good initial scanning point for identification of structures. The parasternal short-axis view should be obtained to assess volume status and exclude regional wall motion abnormalities. The IVC may be evaluated during inspiration and expiration to identify variability and be compared with preoperative assessment, if it was performed. In cooperative and spontaneously breathing patients, the passive leg raise (PLR) maneuver (elevation of the lower extremities to 45 degrees using the patient bed, thereby increasing preload) during IVC ultrasound evaluation has been shown to be a useful adjunct in determining volume responsiveness in the early phases of resuscitation. Whereas PLR is not feasible intraoperatively, it may be useful in the postoperative period. The PLR maneuver provides the heart with a surrogate 500-mL fluid bolus, allowing the clinician to assess for volume-responsive hypotension without increasing the risk of fluid overload. If the patient remains intubated in the PACU, the IVC distensibility index can be examined serially for response to fluid challenges in the mechanically ventilated patient. The remainder of the ultrasound examination, as suggested by Fig 2, should proceed based on the clinical question at hand.

Ultrasound will not provide insight into all possible causes of hypotension, and alternative diagnoses should be considered (eg, medication effects, low systemic vascular resistance [SVR], surgical bleeding, hypothyroidism, adrenal insufficiency).

In the postoperative case scenario, bedside ultrasound may reveal LV wall motion abnormalities or a dilated LV unable to accommodate volume loading, or it may not be revealing in the setting of residual anesthetics and opioids, and signal the need for a low-dose pressor to counteract the SVR decrease.

PERIOPERATIVE ADJUNCTS

Cardiac Arrest

During a cardiac arrest, bedside cardiac ultrasound may reveal the presence of many potentially reversible etiologies (eg, tamponade, pneumothoraces, pulmonary embolism). One of the authors (A.C.A) used focused intraoperative cardiac and lung ultrasound to rapidly diagnose bilateral pneumothoraces as the reversible cause of cardiac arrest in a 9-year-old patient. After the patient’s cardiac arrest, cardiac ultrasound (subcostal 4-chamber view) showed poor LV filling with no evidence of
Lung Ultrasound

Lung ultrasound uses a high-frequency linear array probe to allow for imaging of superficial lung structures. Lung ultrasound relies on the presence of reverberation artifact from moving tissues such as the pleura. Scanning is performed with the probe in the vertical orientation in the mid-clavicular and mid-axillary lines. Lung sliding is the sparkling that is observed rather superficially, resulting from ultrasound reverberating between the visceral and parietal pleurae. Absence of sliding in 2-dimensional scanning or conversion from a seashore to barcode sign in M-mode should raise suspicion for pneumothorax. Large pleural effusions appear as dark fluid with or without lung tissue “floating” within them. Ultrasound has been shown to be as sensitive and specific when compared with computed tomography scanning for pneumothorax and pleural effusion. These pathologic conditions, if hemodynamically significant, should be apparent to a novice sonographer. A detailed explanation of ultrasound imaging of the lungs has been well described by Lichtenstein et al. 

DISCUSSION

Safely using ultrasound as a diagnostic tool requires basic competence in image acquisition and interpretation. Numerous studies have demonstrated that with basic ultrasound training, the average practitioner and even medical student can learn to acquire basic images and recognize clinically significant pathology. With a few hours of training, providers have been shown to be able to reliably assess systolic ventricular function and the presence of significant pericardial effusions. 

There is an abundance of methods for providers to learn ultrasound basics, including live courses, web sites, and high-fidelity simulators. For the novice sonographer, initial education should include an instructed course to learn basic sonographic techniques and image acquisition skills. To become familiar with the appearance of pathologic conditions (eg, ventricular dysfunction and valvulopathies), it is recommended that providers review the widely available libraries of ultrasound images. The ability to recognize clinically significant pathologic conditions can be obtained by thorough review of pre-recorded images. With self teaching, followed by reviewing acquired images with providers skilled in ultrasound, most clinicians should be able to obtain and interpret significant ultrasound findings reliably. The goal in obtaining basic skills is not to quantify the degree of pathology, but to discern severe and potentially high-risk anesthetic findings from less severe pathology. Providers must acquire basic skills and knowledge, allowing them to make focused diagnostic decisions based on bedside ultrasound imaging before application during patient care. Once the basic knowledge is obtained, a credentialing process is important to establish a standard of basic competency. The cornerstones to develop competency for the use of perioperative ultrasound are summarized in Fig 3.

The applicability of bedside ultrasound to anesthetic practice has been recognized; however, formal recommendations for proper credentialing are lacking. The American College of Chest Physicians has suggested criteria for determining basic competence in critical care echocardiography. These criteria include image acquisition of the following views: parasternal long and short-axis, apical and subcostal 4-chamber, and inferior vena cava. These views are recommended to recognize severe hypovolemia, LV and RV failure, tamponade, massive left-sided valvular regurgitation, and cardiac function during and after circulatory arrest. Basic imaging should evaluate the RV and LV for systolic function; volume status; and signs of pericardial effusion, chronic heart disease, gross valvular abnormalities (with and without color Doppler), and intra-cardiac masses.

Conlon et al described a successful credentialing process for implementation of a bedside ultrasound program by novice, non-cardiologist anesthesia and critical care medicine physicians. The process includes completion of an introductory instructional course followed by recording and interpreting “practice” bedside ultrasound scans that are reviewed with practitioners who are expert in sonographic interpretation. After satisfactory review of a predetermined number of ultrasound evaluations, institutional credentialing may be obtained for use of bedside ultrasound in basic diagnostic purposes. The number of supervised ultrasound required to assess competency is undetermined; however, the American College of
Emergency Physicians recommends a minimum of 25 studies be reviewed with experts for credentialing. 66,68 Although certification by an outside organization may not be required for competency, institutional assessment of basic competence and appropriate credentialing are vital before a practitioner uses bedside ultrasound for diagnostic or therapeutic purposes. Until formal credentialing policies for anesthesiologists become established, it is recommended that each institution determine its own policies, while referring to other established guidelines for guidance. 66,68 As always, repeated self assessment and development of continuing medical education related to bedside imaging should be ongoing.

The limitations of transthoracic imaging include the operator-dependent nature of image acquisition and the inability to obtain adequate viewing windows due to patient habitus or positioning limitations. The surgical field also may limit the ability to obtain certain images views intraoperatively, and there may be situations in which transesophageal echocardiography may prove impractical (eg, carotid, head, neck, and esophageal surgery). 69 This approach does not focus on diastology, which is outside the scope of basic imaging and interpretation. 67 Use of focused point-of-care ultrasonography in the perioperative setting is suggested as a clinical tool and certainly is not meant to replace the expertise of cardiologists or formal echocardiographic evaluation. Definitive diagnostic ability requires extensive training and certification in echocardiography. Specifically, with respect to valve examination, the goal is to use ultrasound to increase the sensitivity of identifying patients with significant lesions. The use by novice sonographers will provide many false-negative interpretations; however, with training and review of normal and highly abnormal images, the aim is to have novice clinicians train their eye to identify major pathology.

Application of bedside ultrasound programs in the perioperative setting has been shown to alter the overall course of patient management. 70 Although numerous case reports exist highlighting management changes with single-view perioperative bedside ultrasound use, adoption of bedside ultrasound remains lacking in anesthesia practice and literature. 34,49,69,71–77 There also is no directed approach for the general anesthesiologist regarding a simple and basic guided examination inclusive of lung pathology. Bedside ultrasound should be used perioperatively as an adjunct to the physical examination and should be focused on answering specific clinical questions.

With a greater incorporation of basic ultrasound into anesthesia training curricula, the future of perioperative physical examination may be changing. The availability of compact, affordable, and highly portable ultrasound devices may affect the use of this emerging technology. In the era of enhanced recovery programs, bedside ultrasound certainly can help practitioners guide fluid therapies, potentially reducing morbidity and length of hospital stay.

Because cardiopulmonary complications remain among the leading causes of perioperative mortality, training and use of bedside ultrasound by anesthesia providers are of significant importance for managing and risk-stratifying patients’ cases.

**APPENDIX A. SUPPLEMENTARY MATERIAL**

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1053/j.jvca.2015.11.015.

**REFERENCES**


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