The Use of Point-of-Care Ultrasonography in Trauma Anesthesia

Davinder Ramsingh, MD[a,*], Venkat Reddy Manguntu, MD[b,c]

KEYWORDS

- Perioperative point-of-care ultrasound • Point-of-care ultrasonography in trauma
- Trauma anesthesia • Ultrasound education in anesthesia
- Ultrasound applications for trauma

KEY POINTS

- Management of the trauma patient requires rapid, coordinated care by anesthesiologists using various diagnostic or therapeutic modalities.
- Trauma anesthesiologists must become facile with the use of point-of-care ultrasound (POCUS) to maximize diagnosis and treatment of patients with traumatic injury.
- POCUS can assist in quickly diagnosing a multitude of traumatic injuries and differentiating diagnoses.
- Comprehensive POCUS educational curricula can assist anesthesiology residency programs in teaching residents this vital skillset.
- It is essential to the evolution of the specialty that anesthesiologists and anesthesiology training programs make POCUS education a priority.

INTRODUCTION

Caring for the trauma patient is one of the most complicated and high-risk patient care situations encountered by anesthesiologists. Around the world, trauma is the third leading cause of death overall, with more than 5 million deaths per year.[1] These

Disclosure Statement: Dr D. Ramsingh is a consultant for Edwards Life Sciences; Fujifilm Sonosite; and receives funds for research from General Electric on point-of-care ultrasound and anesthesia delivery systems, Merck Pharmaceuticals, Pacira Pharmaceuticals, Masimo Corporation, and Edwards Lifesciences. Dr V.R. Manguntu has no disclosures.
[a] Department of Anesthesiology, Loma Linda University School of Medicine, Loma Linda University Medical Center, 11234 Anderson Street, MC-2532-D, Loma Linda, CA 92354, USA; [b] Department of Anesthesiology, Division of Cardiovascular Anesthesia, Saint Luke's Mid America Heart Institute, University of Missouri-Kansas City School of Medicine, 4401 Wornall Road, Room 3103, Kansas City, MO 64111, USA; [c] Department of Anesthesiology, Division of Critical Care Medicine, Saint Luke's Mid America Heart Institute, University of Missouri-Kansas City School of Medicine, 4401 Wornall Road, Room 3103, Kansas City, MO 64111, USA
* Corresponding author.
E-mail address: DRamsingh@llu.edu

Anesthesiology Clin 37 (2019) 93–106
https://doi.org/10.1016/j.anclin.2018.09.011 anesthesiology.theclinics.com
1932-2275/19/

patients often present in the middle of the night or on weekends when comprehensive resources and immediate consultation are not available. Therapy is often required for these patients for rapidly developing acute pathologic complications with little to no information on their past medical history. Furthermore, these patients may have rapid alterations to their cardiovascular and pulmonary status, and have a predisposition to occult injuries.

The management of the trauma patient requires rapid and coordinated care by trained physicians. Specialized training in trauma has undergone significant evolution over the past few decades. In 1990, Congress passed the Trauma Care Systems Planning and Development Act that led to the development of organized statewide trauma systems.[2] The American College of Surgeons (ACS) Committee on Trauma identified trauma centers as level I to level V, with the goal of ensuring that adequate resources and trauma-trained physicians are available to treat patients based on their severity of injury.[2] Additionally, the Advanced Trauma Life Support (ATLS) program has been adopted by the ACS and provides organized algorithms and approaches to managing trauma patients.[3]

Parallel to the development of highly reproducible algorithms for the treatment of trauma, ultrasound (US) technology has seen rapid evolution and expansion into emergency medicine (EM) training programs across the nation. EM physicians currently use bedside US for diagnostic and therapeutic purposes (eg, diagnosing hemothorax, retinal detachment). Point-of-care US (POCUS) has revolutionized the practice of emergency physicians.[4] The focused assessment with sonography for trauma (FAST)[5] examination has historically dominated the role of US in trauma management and remains the most studied example of focused clinical US.[6] However, over recent years, academic EM departments have greatly expanded the use of this technology from the periphery of trauma management to now include cardiopulmonary assessment, regional nerve blocks, and transesophageal echocardiography (TEE).

As much as EM has embraced this technology and developed focused applications for US use over the past decade, anesthesiology has lagged behind with regard to broadly adopting US technology. Although most anesthesiologists graduate residency with proficiency in performing US-guided regional anesthesia and vascular access, its use in the perioperative setting to quickly diagnose and aid in the treatment of emergent conditions (eg, pneumothorax, hemothorax, abdominal hemorrhage, hypovolemic or cardiogenic shock) has traditionally not been a focus of anesthesiology residency programs. By and large, anesthesia residents are graduating from residency with no formal education in the use of US for the acute diagnosis of adverse conditions in the perioperative setting.

The growing push for anesthesiologists to advance beyond their role in the intraoperative setting and realize their role as true perioperative physicians has led to the development of the subspecialty of trauma anesthesiology.[2] Since 2013, trauma anesthesiology has been recognized as a distinct subspecialty of anesthesiology by the American Society of Anesthesiologists (ASA).[2] In 2017, the ASA Committee on Trauma and Emergency Preparedness (COTEP) published the results of a survey demonstrating that there was significant disconnect between trauma surgeons and anesthesiologists regarding whether the anesthesiologists at their respective institutions were appropriately trained to manage trauma patients.[7] Trauma anesthesiologists must be prepared to emergently care for a patient with any severity of injury and must be adept at using the same management approaches described in the ATLS program. Development of POCUS curricula within anesthesiology residency programs is of paramount importance in the training of trauma anesthesiologists. This article reviews the topics of POCUS that are relevant to the perioperative trauma patient by reviewing the utility of POCUS for each category of the ATLS algorithm.

AIRWAY MANAGEMENT

The utility of POCUS for airway management has been demonstrated for the identification of difficult laryngoscopy, appropriate location of the endotracheal tube, and to facilitate cricothyrotomy or tracheostomy procedures.

Difficult Laryngoscopy and Endotracheal Tube Localization

POCUS has been demonstrated to improve the airway examination. Recently, Reddy and colleagues[8] found that anterior neck soft tissue thickness at the level of the vocal cords is a predictor of difficult airway. In addition to use of US for visualization of the hyoid bone, decreased temporomandibular joint mobility, measurement of the hyomental distance with neck extension, and the measurement of anterior soft tissue thickness at the thyrohyoid membrane have all been used to predict difficult airways.[9]

Endotracheal Tube Localization

US has demonstrated utility for verification of successful endotracheal intubation, reporting sensitivity and specificity of 100% versus esophageal intubation.[10] Because this is likely less of a concern in the perioperative setting, US has also demonstrated the ability to detect tracheal versus endobronchial intubation. Studies have demonstrated a higher degree of sensitivity and specificity (>93%) with POCUS than with auscultation.[11]

Cricothyrotomy or Tracheostomy

The use of surface landmarks to identify the cricothyroid membrane may be difficult, particularly for obese and female patients.[12,13] Bedside US is a reliable modality for rapid identification of anatomy for emergent cricothyrotomy.[14,15] Similarly, US has demonstrated improved success in accessing the trachea with more than 90% first-pass attempts.[16] The use of POCUS for percutaneous tracheostomies has demonstrated improved accuracy and has also been suggested to decrease complication rates.[17,18]

BREATHING OR PULMONARY

The ability of US to provide insight into pulmonary disease was previously thought to be impossible secondary to the acoustic impedance difference with aerated tissue. However, recent evidence has demonstrated POCUS to be extremely useful in establishing a differential diagnosis for acute respiratory failure in the postoperative period.[19] POCUS has proven to be faster and superior to chest radiograph (CXR) in diagnosing pneumothorax, pleural effusion, and alveolar interstitial diseases.[20,21] Ford and colleagues[22] recently demonstrated the ability of POCUS to detect perioperative pulmonary disease (atelectasis, consolidation, alveolar-interstitial syndrome, pleural effusion, and pneumothorax) in patients undergoing cardiac surgery with a high degree of specificity to CXR and physical examination findings. However, it is important to stress that a significant portion of pulmonary US deals with the detection and recognition of artifact generated by pathologic complications. This key point makes pulmonary US a challenging topic for the novice POCUS user.

Evaluation of Pneumothorax

US is highly accurate at detecting pneumothorax.[20,21] The primary US feature is the abolition of lung sliding, which is defined as the motion of visceral pleura against the parietal pleura during respiration. Importantly, this nonspecific finding is seen in several other conditions, such as malignancy, chronic obstructive pulmonary disease, and pneumonia. Additionally, it only detects pneumothoraces at the location at which the operator is scanning, thus it has the potential to miss pneumothoraces present at different scan locations. To this effect, it is important to scan the lung fields in more than one location. More specifically, it is the visualization of a lung point that is pathognomonic for pneumothorax. The lung point is the point at which the visceral pleura and parietal pleura separate. In a pneumothorax, both pleural layers separate. Tracing the pleural layer separation back to a lung point (point of separation) confirms that the lack of lung sliding is due to pneumothorax and not another disease process.

Parenchymal Lung Diseases

POCUS has demonstrated the same high degree of sensitivity for the detection of airspace disease within the lung parenchyma. Common practice in POCUS involves detecting artifacts generated from the disease developing within the lung parenchyma. Specifically, parenchyma diseases (edema, pneumonia, inflammation) will cause the interlobular septa to thicken, producing long vertical lines through the lung parenchyma on US imaging. This is commonly referred to as an US lung comet (ULC) (**Fig. 1**). Recent studies have demonstrated that the presence of greater than 9 ULCs per lung field is associated with 100% specificity for cardiogenic dyspnea.[23] Multiple protocols have been developed regarding pulmonary POCUS, mostly in the critical care setting. Of these, the bedside lung US in emergency (BLUE) protocol stands out as a comprehensive approach to rapidly facilitate the diagnosis of a patient in acute respiratory failure.[24]

Assessment for Pleural Effusion

US is more sensitive and specific than auscultation or CXR and is, therefore, the method of choice in detecting pleural effusion.[25,26] Effusions greater than 1 cm are easily detected and have a greater than 90% sensitivity and specificity for pleural effusion.[26] The utility for POCUS to guide thoracentesis has also been suggested.[27]

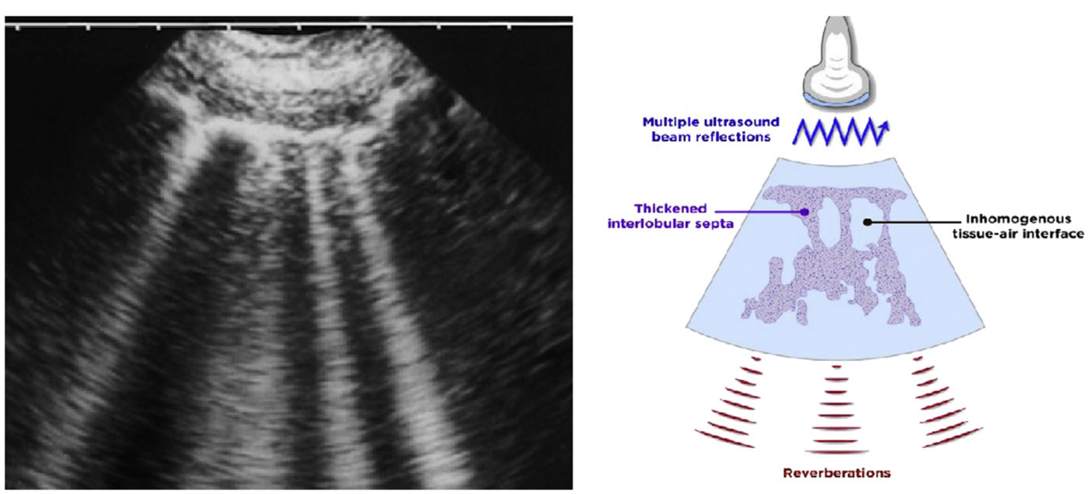

Fig. 1. ULC of pulmonary airspace disease.

CIRCULATION

POCUS has proven to be critical in the assessment of causes of hemodynamic instability and shock. Beyond assessing the patient's volume status, POCUS allows the anesthesiologist to differentiate between causes of shock and assess for injuries that may be leading to a shock state.

The following sections review the methods commonly used in POCUS that address these topics.

MECHANISMS OF HYPOTENSION

The FAST examination is the most widely used POCUS examination currently practiced in the acute care setting. This examination has been shown to very reliably detect greater than 200 mL of blood or fluid in body cavities (abdomen, pleural space, and pericardium) and it is a highly effective tool in the detection of clinically significant hemoperitoneum and hemopericardium in unstable patients.[5,28–30] Both trauma patients and patients in the postoperative care unit may have injuries that can cause significant blood loss and remain undetected by physical examination. The application of this examination allows the perioperative physician to determine if hemodynamic instability is secondary to pericardial and/or peritoneal injury, resulting in free fluid that can occur before or after surgery. Trauma patients can also sustain direct injury to their thoracic structures, such as the aorta or myocardium. A penetrating injury to the chest, for instance, may demonstrate an injury to the RV free wall, leading to a large pericardial effusion and tamponade. Additionally, elderly trauma patients with underlying ischemic heart disease are at risk for myocardial injury. POCUS can reveal new regional wall motion abnormalities in patients with previously normal cardiac function. In this way, obstructive (tamponade), hemorrhagic or hypovolemic, and cardiogenic causes of shock can quickly be elucidated by the perioperative physician.

Assessment of Cardiac Function

Transthoracic echocardiography (TTE) examination of the cardiopulmonary system using bedside POCUS technology has proven to be a reliable tool when compared with formal echocardiography.[31] Indeed, assessments of global left ventricular (LV) function, have shown a strong correlation ($r \geq 0.92$) between POCUS and formal echocardiography examinations.[31] Similarly, good correlation between POCUS and formal echocardiography was also shown when assessing right ventricular (RV) function and valvular function (excluding aortic stenosis) ($r > 0.81$).[31] Additional support for bedside TTE has been demonstrated in patients with shock in which adequate image quality was obtained in 99% of cases with a sensitivity and specificity approaching 100% and 95%, respectively, for identifying a cardiogenic cause for shock. Finally, it has been demonstrated that noncardiologists can be trained to perform and interpret a limited transthoracic examination focused on assessment of LV function.[32,33] Relatively straightforward measures of LV function can be obtained by obtaining parasternal short-axis views of the LV. By obtaining a parasternal short-axis view of the LV at the level of the papillary muscles, the operator can record a 2 to 4 beat video clip. The LV end-diastolic area (LVEDA) (**Fig. 2**A) and LV end-systolic area (LVESA) (**Fig. 2**B) can both be obtained by tracing the endocardial border using the trace function on the US. From this point, using the area measurements obtained, the fractional area change (FAC) can be calculated as follows:

$$FAC = [LVEDA - LVESA]/LVEDA.$$

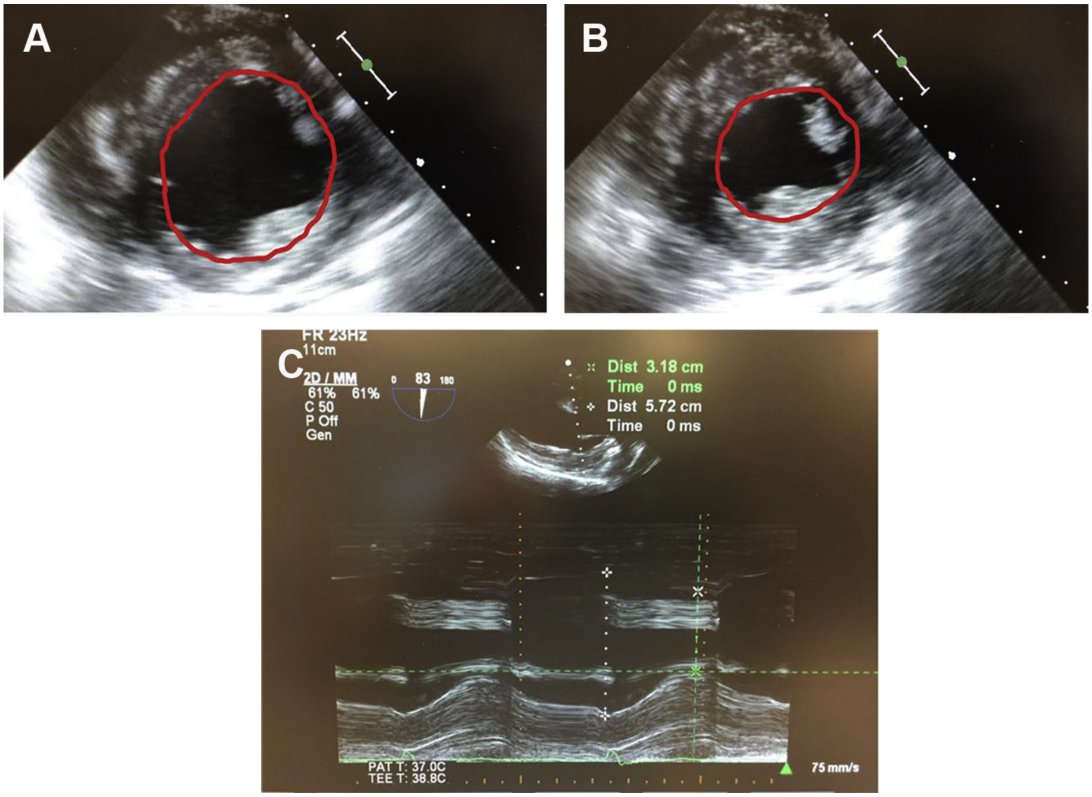

Fig. 2. Parasternal short-axis imaging. (*A*, *B*) Tracing of LVEDA and LVESA to calculate fractional area change and (*C*) M-mode to calculate fractional shortening. The red circle is a tracing of endocardial border in diastole (*A*) and systole (*B*). The green line is a tracing of the endocardial diameter in Motion Mode (*C*).

FAC is a two-dimensional assessment of LV function. A normal value ($\geq$50%) correlates to a normal LV ejection fraction ($\geq$55%). Alternatively, another basic measure of LV function, fractional shortening (FS), can also quickly be obtained from the same parasternal short-axis view, or the parasternal long-axis view just beyond the mitral valve at the level of the chordae tendineae. After this view is obtained, the Motion-mode beam is placed through the LV (**Fig. 2**C), taking care not to include the papillary muscles. Using the caliper tool on the US, the LV end-diastolic diameter (LVEDd) (5.72 cm in **Fig. 2**C) and LV end-systolic diameter (LVESd) (3.18 cm in **Fig. 2**C) are measured and the following equation is used:

FS = [LVEDd – LVESd]/LVEDd.

FS values greater than 30% are considered normal LV function. It is important to remember that both these measurements, FAC and FS, are affected by regional wall motion abnormalities. Additionally, FAC is essentially a 2-dimensional measurement and FS is a 1-dimensional measurement. Therefore, although they are useful insofar as providing a quick generalized assessment of LV systolic function, they do not provide a complete picture. The previous assessments are basic measures of systolic function and can be done by perioperative physicians with basic US training. Recently, guidelines have been published for cardiac POCUS by noncardiologists for the intensive care setting.[33] These guidelines can also be extended to the perioperative arena.

Volume Status

The concept of goal-directed fluid therapy is based on the evidence that either too little or too much fluid administration during the perioperative period can worsen a patient's clinical picture and/or organ function.[34] POCUS provides several techniques to assess static and dynamic indices of volume status. Regarding static indices, the diameter of the inferior vena cava (IVC) and its percent collapsibility from a maximal negative inspiratory breath has been shown to correlate to central venous pressures.[35,36] Another modality that can elucidate the volume status of a patient involves the direct measurement of LVEDA from a parasternal short-axis view (see **Fig. 2**A). Several studies have shown its utility in helping predict preload.[37–39]

Although these static parameters may be more reliable than urine output or other traditional identifiers of hypovolemia, they may not always predict fluid responsiveness. The Frank-Starling curve is an excellent depiction of the relationship between preload and cardiac output (**Fig. 3**). For increasing preload, cardiac output will increase to a point, after which no measurable increases in cardiac output will occur. Dynamic flow parameters are used to identify where on the Frank-Starling curve a patient exists. A patient on the steep portion (point A; see **Fig. 3**) of the Frank-Starling curve will respond to fluid by generating greater cardiac output (fluid-responsive). Alternatively, if the patient is on the flat portion of the curve (point B; see **Fig. 3**) there will be minimal increases in cardiac output for any further increases in preload. To assess a patient's location on the Frank-Starling curve and volume responsiveness, measurements must be made over several cardiac cycles. Patients subject to positive-pressure ventilation undergo regular changes in intrathoracic pressure that change loading conditions in the cardiovascular system. The greater the degree of intravascular volume depletion, the greater the effect positive-pressure ventilation has on RV (thereby LV) preload. Ideally, measurements are made before and after a volume challenge to assess for degree of response.

POCUS affords us several modalities to evaluate fluid responsiveness. Assessment of the IVC diameter change secondary to the mechanical ventilatory cycle has shown to predict fluid responsiveness. Specifically, the IVC diameter at end-expiration (D_{min}) and the IVC diameter at end-inspiration (D_{max}) can be measured to calculate the distensibility index of the IVC (dIVC) (**Fig. 4**A). Using a threshold dIVC of 18%, responders and nonresponders were discriminated with 90% sensitivity and 90% specificity in trauma patients presenting in shock.[40] More intricate dynamic methods of using POCUS to determine volume status include the use of Doppler ultrasonography (pulse-wave Doppler) to measure the stroke distance, which is termed velocity time

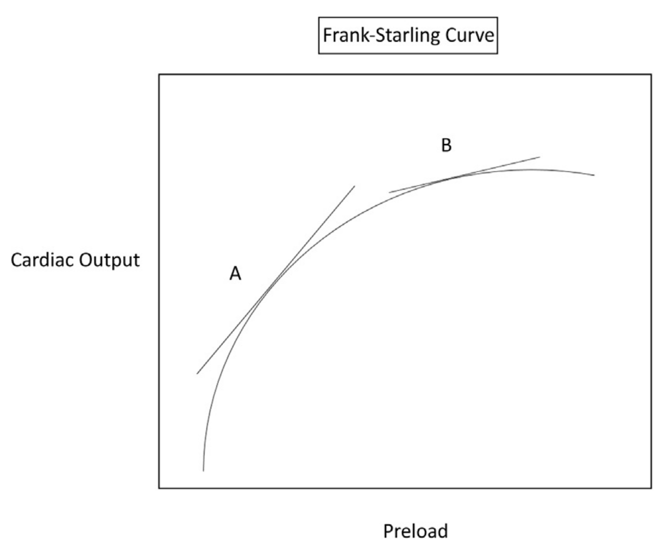

Fig. 3. Frank-Starling curve. Relationship between preload and cardiac output.

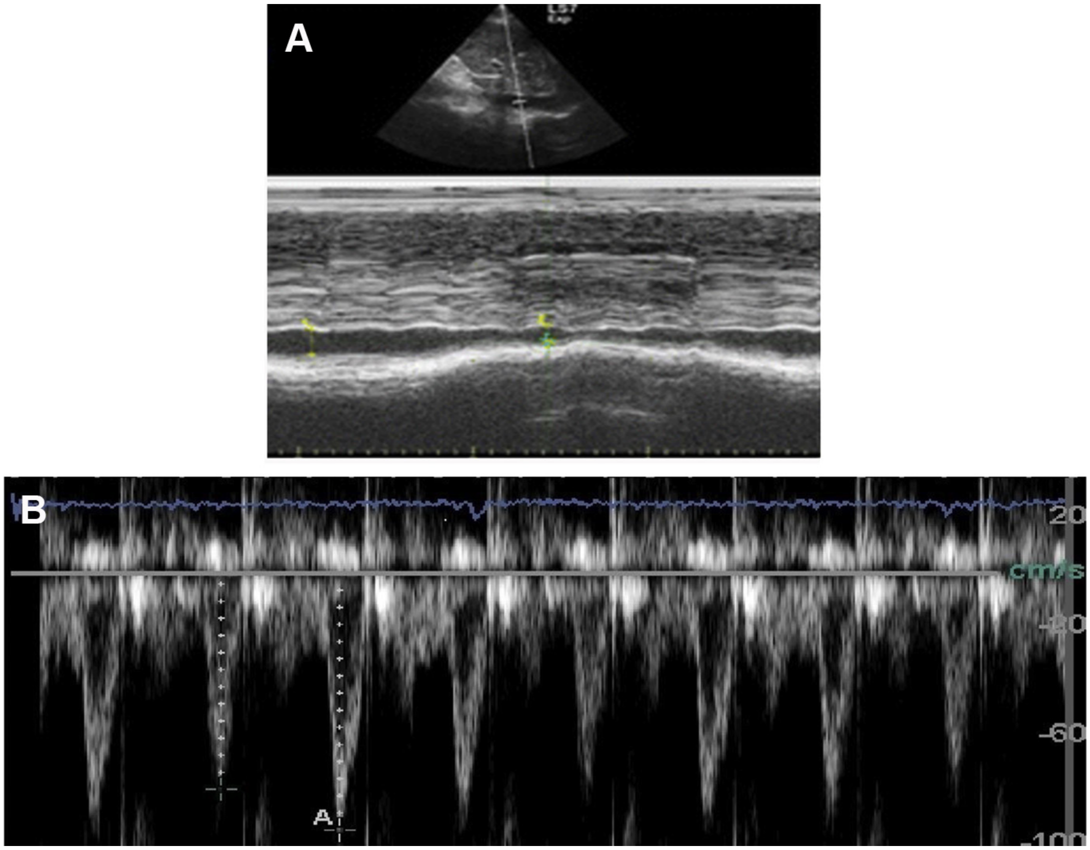

Fig. 4. US methods of volume status. (*A*) IVC collapsibility. (*B*) Doppler ultrasonography: velocity time integral variation.

integral (VTI), for the LV outflow tract (LVOT) or aorta. The stroke distance is essentially the measurement of the distance a volume of blood is moved, from point A to point B, with each ventricular contraction. By multiplying the stroke distance or VTI by the cross-sectional area of the tube through which the blood is flowing (LVOT in this example), the stroke volume (SV) is determined. Assuming no acute changes in LV contractility occur, the SV or LVOT VTIs can be compared during the inspiratory and expiratory phases of mechanical positive-pressure ventilation. A change in SV or VTI across LVOT during mechanical ventilation has been shown to indicate fluid responsiveness (**Fig. 4**B).[41,42] Likewise, the perioperative physician can ascertain where on the Frank-Starling curve their patient exists (volume-responsive steep segment or volume-nonresponsive flat segment) by measuring the SV or VTI before and after a fluid challenge. If a fluid challenge is given and the change in SV or VTI across the LVOT before and after is minimal, the patient is unlikely to respond to escalating amounts of fluid therapy.

DISABILITY OR NEUROLOGIC ASSESSMENT

There are many emerging areas in which POCUS can assist in the neurologic assessment of trauma patients. Probably among the most validated topics is using POCUS to estimate intracranial pressure (ICP) values. Visualizing the optic nerve sheath (ONS) and then measuring the ONS diameter has been shown to provide a rapid and accurate assessment of whether ICP is elevated. The ONS is contiguous with the dura mater and has a trabeculated arachnoid space through which cerebrospinal fluid circulates. The relationship between the ONS diameter (ONSD) and ICP has been well established.[43,44] The sensitivity for US in detecting elevated ICP was 100% (95% CI 68%–100%) and specificity was 63% (95% CI 50%–76%). An ONSD of greater than 5 mm, at a point approximately 2 mm from the retina, suggests elevated ICP. Additionally, rapid assessment of the retina and vitreous can reveal any obvious retinal detachment or vitreous hemorrhage that may have occurred due to trauma.

EXPOSURE OR ENVIRONMENT CONTROL

Gastric Content

The ability of POCUS to determine the volume of gastric content has emerged as a validated technique.[45] Perlas and colleagues[45] suggested that the presence of fluid in the gastric antrum identified on US in both the supine and right lateral decubitus positions may help identify patients at increased risk of aspiration. US can differentiate between solid and clear liquid stomach contents, with more particulate contents being associated with worsened outcomes if aspirated. Although healthy fasting patients may have gastric volumes of up to 1.5 mL/kg with minimal risk of aspiration, the visualization of gastric antrum fluid volumes of greater than 180 mL suggests patients may be at an increased risk for aspiration. The ability to detect gastric volume via POCUS may prove to be a valid method to aid in assessing aspiration risk, as well as determining if elective surgeries should be postponed based on the US examination findings.

Advanced Vascular Access

The use of US to assist with vascular access has advanced beyond its now widespread use for central venous access. Specifically, US has proven to reliably aid in the placement of difficult intravenous[46,47] and intraarterial catheters.[48,49] Use of US for peripheral venous access has also been shown to significantly increase success rates.[50] At the Mid America Heart Institute, US-guided access of the basilic vein and introduction of a guidewire followed by threading of a 4F vascular access sheath has reliably allowed preservation of the central veins for future access in patients with limited vascular access. A recent meta-analysis was conducted to compare US-guided and anatomic landmark-guided techniques for central venous catheter placement. The results demonstrated a decreased risk of cannulation failure, arterial puncture, hematoma, and hemothorax with the US-guided placement technique.[51]

In addition to US-guided vascular catheter placement, the Mid America Heart Institute's critical care and cardiovascular anesthesia providers use both POCUS and TEE to assist in the management of cardiac arrest and refractory acute respiratory distress syndrome (ARDS). TEE-guided insertion of a bicaval dual-lumen catheter into the right internal jugular vein by cardiac critical care anesthesiologists facilitates rapid transition to venovenous extracorporeal membrane oxygenation (ECMO) in severe ARDS. Similarly, during cardiac arrest and early cardiopulmonary resuscitation refractory to standard ACLS protocols, POCUS is used to guide the rapid placement of guidewires into the right femoral vein and left femoral artery for potential venoarterial ECMO cannulation by cardiothoracic surgeons in the operating room, if patients are candidates.

Evaluation of Deep Vein Thrombosis and Pulmonary Embolus

The current standard for evaluation of patients with suspected deep vein thrombosis or pulmonary embolus often involves lower compression ultrasonography and computed tomography pulmonary angiography. These tests are often performed despite low pretest probability and the long time to perform and obtain the results of these tests may contribute to diagnostic delays. Recent evidence supports that the use of a focused POCUS examination, performed by intensivists, involving lung US for subpleural infarcts, assessment for RV dilatation by cardiac US, and assessment for pulmonary embolus by leg vein US, can provide a high degree of sensitivity (90%) and specificity (86.2%) for the detection of pulmonary embolus.[52]

BRINGING THESE MODALITIES TO TRAUMA ANESTHESIOLOGISTS

Although it is encouraging to see the expansion of perioperative POCUS (P-POCUS), there remains the potential for tremendous growth with respect to the application of POCUS in trauma patient care. Other specialties have developed formalized educational and certification pathways.[53] EM has adopted POCUS training as a core competency for residency training and provides a year of fellowship training in clinical US. Of note, a similar interest in P-POCUS education has been reported by anesthesiology residents.[54]

Integration of comprehensive P-POCUS curricula has been developed for anesthesia residency training but is currently not widely adopted. The 2018 Accreditation Council for Graduate Medical Education program requirements for anesthesiology, however, now require "competency in using surface ultrasound and transesophageal and transthoracic echocardiography to guide the performance of invasive procedures and to evaluate organ function and pathology as related to anesthesia, critical care and resuscitation."[55] This change in educational requirements will encourage residency programs to adopt existing P-POCUS curricula. However, the effectiveness and efficacy of implementing P-POCUS into anesthesiology training program curricula remains to be determined. The implementation of POCUS training into anesthesiology residency programs still faces many obstacles, especially without standardized training protocols. It may take years for POCUS curricula to be effectively carried out and demonstrate proficient clinical skill levels and knowledge among trainees.

One study evaluated the utility of implementing a comprehensive POCUS educational curriculum for anesthesia residency training called Focused Perioperative Risk Evaluation Sonography Involving Gastro-Abdominal Hemodynamic and Transthoracic US (FORESIGHT). This curriculum incorporated the topics of

1. Cardiac
2. Pulmonary
3. Hemodynamic
4. Gastro-abdominal
5. Airway
6. Vascular access
7. ICP assessment

In this single-center study, implementation of the curriculum into residency training demonstrated statistical significance for positive participant satisfaction, improved knowledge, and acquisition of hands-on skills as evaluated via the Kirkpatrick assessment tool.[54] Additionally, a positive clinical impact was also suggested after 1 year of training. To further P-POCUS education, this curriculum is now online and provides open access, under a Creative Commons license (www.foresightultrasound.com).

This is among several initiatives to further the development of P-POCUS. Other initiatives include the focus-assessed TTE (FATE) protocol (http://usabcd.org), which was developed by an anesthesiologist and is among the most widely referenced POCUS examination protocols. Additional online resources available for education on P-POCUS include those from the Society of Critical Care Medicine (http://www.sccm.org/Education Center/Ultrasound/Pages/default.aspx), the American Institute of Ultrasound (http://www.aium.org), and various Continuing Medical Education training programs.[53]

Although these resources are important, the onus is on anesthesiologists to develop structured guidelines, endorsed educational pathways, and certified credentialing processes to incorporate P-POCUS into everyday practice. With the evolution of anesthesiology from a specialty relegated to the operative theater and intensive care units to a comprehensive perioperative role, anesthesiologists must embrace US technology and become leaders and educators in the development of new applications of this technology.

REFERENCES

1. American Association for the Surgery of Trauma; 2018. Available at: http://www.aast.org/trauma-facts. Accessed November 2, 2018.
2. Delegates ASoAHo. Statement of principles: trauma anesthesiology. American Society of Anesthesiologists House of Delegates; 2013. Available at: https://www.asahq.org/resources/resources-from-asa-committees/committee-on-trauma-and-emergency-preparedness/trauma-anesthesiology. Accessed November 2, 2018.
3. The Advanced Trauma Life Support. 2008. Available at: https://www.facs.org/quality-programs/trauma/atls.
4. 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:S126–30.
5. Rozycki GS, Ochsner MG, Schmidt JA, et al. A prospective study of surgeon-performed ultrasound as the primary adjuvant modality for injured patient assessment. J Trauma 1995;39:492–8 [discussion: 498–500].
6. Gillman LM, Ball CG, Panebianco N, et al. Clinician performed resuscitative ultrasonography for the initial evaluation and resuscitation of trauma. Scand J Trauma Resusc Emerg Med 2009;17:34.
7. Kaslow O, Kuza CM, McCunn M, et al. Trauma anesthesiology as part of the core anesthesiology residency program training: expert opinion of the American Society of Anesthesiologists Committee on Trauma and emergency preparedness (ASA COTEP). Anesth Analg 2017;125:1060–5.
8. Reddy PB, Punetha P, Chalam KS. Ultrasonography - a viable tool for airway assessment. Indian J Anaesth 2016;60:807–13.
9. Fulkerson JS, Moore HM, Anderson TS, et al. Ultrasonography in the preoperative difficult airway assessment. J Clin Monit Comput 2017;31:513–30.
10. Muslu B, Sert H, Kaya A, et al. Use of sonography for rapid identification of esophageal and tracheal intubations in adult patients. J Ultrasound Med 2011;30:671–6.
11. Ramsingh D, Frank E, Haughton E, et al. Auscultation versus point of care ultrasound to determine endotracheal versus bronchial intubation: a diagnostic accuracy study. Anesthesiology 2016;124(5):1012–20.
12. Elliott DS, Baker PA, Scott MR, et al. Accuracy of surface landmark identification for cannula cricothyroidotomy. Anaesthesia 2010;65:889–94.
13. Aslani A, Ng SC, Hurley M, et al. Accuracy of identification of the cricothyroid membrane in female subjects using palpation: an observational study. Anesth Analg 2012;114:987–92.

14. Nicholls SE, Sweeney TW, Ferre RM, et al. Bedside sonography by emergency physicians for the rapid identification of landmarks relevant to cricothyrotomy. Am J Emerg Med 2008;26:852–6.
15. Osman A, Sum KM. Role of upper airway ultrasound in airway management. J Intensive Care 2016;4:52.
16. Kleine-Brueggeney M, Greif R, Ross S, et al. Ultrasound-guided percutaneous tracheal puncture: a computer-tomographic controlled study in cadavers. Br J Anaesth 2011;106:738–42.
17. Rudas M, Seppelt I, Herkes R, et al. Traditional landmark versus ultrasound guided tracheal puncture during percutaneous dilatational tracheostomy in adult intensive care patients: a randomised controlled trial. Crit Care 2014;18:514.
18. Yavuz A, Yilmaz M, Goya C, et al. Advantages of US in percutaneous dilatational tracheostomy: randomized controlled trial and review of the literature. Radiology 2014;273:927–36.
19. Lee FC. Lung ultrasound-a primary survey of the acutely dyspneic patient. J Intensive Care 2016;4:57.
20. Xirouchaki N, Magkanas E, Vaporidi K, et al. Lung ultrasound in critically ill patients: comparison with bedside chest radiography. Intensive Care Med 2011; 37:1488–93.
21. 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.
22. Ford JW, Heiberg J, Brennan AP, et al. A pilot assessment of 3 point-of-care strategies for diagnosis of perioperative lung pathology. Anesth Analg 2017;124(3): 734–42.
23. Gargani L, Frassi F, Soldati G, et al. Ultrasound lung comets for the differential diagnosis of acute cardiogenic dyspnoea: a comparison with natriuretic peptides. Eur J Heart Fail 2008;10:70–7.
24. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 2008;134:117–25.
25. Doust BD, Baum JK, Maklad NF, et al. Ultrasonic evaluation of pleural opacities. Radiology 1975;114:135–40.
26. Lichtenstein D, Goldstein I, Mourgeon E, et al. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology 2004;100:9–15.
27. Lichtenstein D, Hulot JS, Rabiller A, et al. Feasibility and safety of ultrasound-aided thoracentesis in mechanically ventilated patients. Intensive Care Med 1999;25:955–8.
28. Scalea TM, Rodriguez A, Chiu WC, et al. Focused assessment with sonography for trauma (FAST): results from an international consensus conference. J Trauma 1999;46:466–72.
29. Rose JS. Ultrasound in abdominal trauma. Emerg Med Clin North Am 2004;22: 581–99, vii.
30. Kirkpatrick AW, Sirois M, Laupland KB, et al. Prospective evaluation of hand-held focused abdominal sonography for trauma (FAST) in blunt abdominal trauma. Can J Surg 2005;48:453–60.
31. Andersen GN, Haugen BO, Graven T, et al. Feasibility and reliability of point-of-care pocket-sized echocardiography. Eur J Echocardiogr 2011;12:665–70.
32. Manasia AR, Nagaraj HM, Kodali RB, et al. Feasibility and potential clinical utility of goal-directed transthoracic echocardiography performed by noncardiologist

intensivists using a small hand-carried device (SonoHeart) in critically ill patients. J Cardiothorac Vasc Anesth 2005;19:155–9.
33. Mazraeshahi RM, Farmer JC, Porembka DT. A suggested curriculum in echocardiography for critical care physicians. Crit Care Med 2007;35:S431–3.
34. Bundgaard-Nielsen M, Holte K, Secher NH, et al. Monitoring of peri-operative fluid administration by individualized goal-directed therapy. Acta Anaesthesiol Scand 2007;51:331–40.
35. Ommen SR, Nishimura RA, Hurrell DG, et al. Assessment of right atrial pressure with 2-dimensional and Doppler echocardiography: a simultaneous catheterization and echocardiographic study. Mayo Clin Proc 2000;75:24–9.
36. Prekker ME, Scott NL, Hart D, et al. Point-of-care ultrasound to estimate central venous pressure: a comparison of three techniques. Crit Care Med 2013;41:833–41.
37. Cannesson M, Slieker J, Desebbe O, et al. Prediction of fluid responsiveness using respiratory variations in left ventricular stroke area by transoesophageal echocardiographic automated border detection in mechanically ventilated patients. Crit Care 2006;10:R171.
38. Scheuren K, Wente MN, Hainer C, et al. Left ventricular end-diastolic area is a measure of cardiac preload in patients with early septic shock. Eur J Anaesthesiol 2009;26:759–65.
39. Subramaniam B, Talmor D. Echocardiography for management of hypotension in the intensive care unit. Crit Care Med 2007;35:S401–7.
40. Sefidbakht S, Assadsangabi R, Abbasi HR, et al. Sonographic measurement of the inferior vena cava as a predictor of shock in trauma patients. Emerg Radiol 2007;14:181–5.
41. Broch O, Renner J, Gruenewald M, et al. Variation of left ventricular outflow tract velocity and global end-diastolic volume index reliably predict fluid responsiveness in cardiac surgery patients. J Crit Care 2012;27:325.e7-13.
42. Charron C, Caille V, Jardin F, et al. Echocardiographic measurement of fluid responsiveness. Curr Opin Crit Care 2006;12:249–54.
43. Hansen HC, Helmke K. Validation of the optic nerve sheath response to changing cerebrospinal fluid pressure: ultrasound findings during intrathecal infusion tests. J Neurosurg 1997;87:34–40.
44. Tayal VS, Neulander M, Norton HJ, et al. Emergency department sonographic measurement of optic nerve sheath diameter to detect findings of increased intracranial pressure in adult head injury patients. Ann Emerg Med 2007;49:508–14.
45. Perlas A, Van de Putte P, Van Houwe P, et al. I-AIM framework for point-of-care gastric ultrasound. Br J Anaesth 2016;116:7–11.
46. Costantino TG, Parikh AK, Satz WA, et al. Ultrasonography-guided peripheral intravenous access versus traditional approaches in patients with difficult intravenous access. Ann Emerg Med 2005;46:456–61.
47. Keyes LE, Frazee BW, Snoey ER, et al. Ultrasound-guided brachial and basilic vein cannulation in emergency department patients with difficult intravenous access. Ann Emerg Med 1999;34:711–4.
48. Ashworth A, Arrowsmith JE. Ultrasound-guided arterial cannulation. Eur J Anaesthesiol 2010;27:307.
49. Shiver S, Blaivas M, Lyon M. A prospective comparison of ultrasound-guided and blindly placed radial arterial catheters. Acad Emerg Med 2006;13:1275–9.
50. Stolz LA, Stolz U, Howe C, et al. Ultrasound-guided peripheral venous access: a meta-analysis and systematic review. J Vasc Access 2015;16(4):321–6.

51. Wu SY, Ling Q, Cao LH, et al. Real-time two-dimensional ultrasound guidance for central venous cannulation: a meta-analysis. Anesthesiology 2013;118:361–75.
52. Nazerian P, Vanni S, Volpicelli G, et al. Accuracy of point-of-care multiorgan ultrasonography for the diagnosis of pulmonary embolism. Chest 2014;145:950–7.
53. Mahmood F, Matyal R, Skubas N, et al. Perioperative ultrasound training in anesthesiology: a call to action. Anesth Analg 2016;122:1794–804.
54. Ramsingh D, Rinehart J, Kain Z, et al. Impact assessment of perioperative point-of-care ultrasound training on anesthesiology residents. Anesthesiology 2015;123:670–82.
55. ACGME program requirements for graduate medical education in anesthesiology. Suite 2000, 401 North Michigan Avenue, Chicago, IL 60611. 2018. p. 17–8. Available at: https://www.acgme.org/Portals/0/PFAssets/ProgramRequirements/040Anesthesiology2018.pdf?ver=2018-06-14-142529-527. Accessed July 24, 2018.