The Evolving Role of Ultrasound in Prehospital and Emergency Medicine

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KEYWORDS

• POCUS • Ultrasound • Prehospital • Emergency medicine • Diagnostic
• Procedural

KEY POINTS

- Point-of-care ultrasound (POCUS) is rapidly expanding in access and utility in emergency medicine for the diagnosis and treatment of a wide range of clinical conditions.
- There are several high-yield applications of POCUS in emergency medicine.
- POCUS has been shown to aid in evaluation and treatment of patients in several emergency scenarios.
- Multiple trials have shown integration of POCUS in prehospital care as feasible.
- The use of POCUS should be done within a specific clinical context to answer specific diagnostic questions. In the prehospital and emergency medicine setting, POCUS can rapidly answer binary questions pertaining to a critically ill or injured patient.

INTRODUCTION

Bedside ultrasound has become an essential tool for emergency medicine (EM) providers for the evaluation and treatment of patients in the emergency department (ED). Recently, studies have looked at the use of ultrasound to aid in prehospital care (PHC) including augmenting resuscitation protocols and early identification of critical disease states. As ultrasound equipment becomes more affordable and portable and more studies show the diagnostic and procedural utility of sonography, it is likely to have a growing number of applications which could make the ultrasound probe as common as the stethoscope.[1,2]

Ultrasound is no longer only used by trained technicians and radiologists to confirm diagnoses and aid in procedures with ultrasonography now being done at the bedside

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Abbreviations	
POCUS	Point-of-care Ultrasound
PHC	Prehospital care
EM	Emergency medicine
ED	Emergency department
ATLS	Advanced trauma life support
CPR	Cardiopulmonar resuscitation
PEA	Pulseless electrical activity

rather than only in radiology suites. The term point-of-care ultrasonography (POCUS) has been defined as "the acquisition, interpretation, and immediate clinical integration of ultrasonographic imaging performed by a treating clinician at the patient's bedside rather than by a radiologist or cardiologist."[3]

The use of POCUS requires successful acquisition of images at the bedside including probe selection, placement, and manual manipulation to obtain useful images which is a skill that requires repetition and practice. In addition, users must understand the basic physics of the ultrasound waves and the numerous ways to adjust, manipulate, and capture images. This is known as "knobology,"[4]referring to the standard knobs and buttons of traditional machines that are rapidly being replaced by touchscreens.

Experience is also needed obtaining as well as interpreting sonographic images in real time at the bedside. Like other radiographic studies, knowledge of normal anatomic structures and pathologic states are needed to successfully interpret the images obtained. This requires further training beyond the technical and manual skills needed to clearly visualize subcutaneous structures. Thus, the implementation of POCUS into clinical care requires education and training on the use of the ultrasound machine and manual manipulation of the ultrasound probe to obtain images while simultaneously interpreting those images and applying it to the clinical scenario at hand.

HISTORY

Before the routine use of ultrasound in the ED at the bedside, sonography had and continues to be used as a diagnostic test with images obtained by trained technicians and interpreted by experts, including radiologists and cardiologists. Trained interventional radiologists also use ultrasound in therapeutic procedures. Today, many EM providers are integrating POCUS into clinical care for immediate diagnostic purposes as well as visualization prior or during common procedures.[3]

The role of POCUS in the ED continues to evolve[5] as technology advances and more literature on the subject is published. Research has shown the value of POCUS at the bedside in a variety of settings in the hospital,[3] which has expanded to the field including the use of POCUS in the evaluation and management of patients in the field and during transport by emergency medical services (EMS) in the prehospital setting.[6]

POINT-OF-CARE ULTRASOUND IN PATIENT ASSESSMENT

POCUS has been shown to significantly change diagnosis and treatment,[7] although it should always be done within the training, experience, and scope of practice of the practitioner. There are limitations in its use including patient factors such as bowel gas or body habitus that can obscure useful images as well as findings that must be carefully considered when making diagnostic or therapeutic decisions.

POCUS can be thought of as an adjunct to the physical examination, like auscultation with a stethoscope, or it can be used as a bedside test to provide more data about a potential diagnosis, such as obtaining a bedside glucose reading in the assessment of altered mental status. In either approach, it is important to know the meaning and significance of POCUS findings and the limitations of its use. For example, just as a heart murmur is rarely diagnostic alone, a singular POCUS finding is rarely pathognomonic. Similarly, when interpreting POCUS as a test, the sensitivity and specificity must be considered when formulating the most likely diagnosis. POCUS must always be used in conjunction with the clinical picture and probability of the diagnosis in question.

HIGH-YIELD POINT-OF-CARE ULTRASOUND

The use of POCUS to reliably detect a finding that results in a change in the diagnosis or treatment of a patient can be considered high yield. This includes both *emergent* applications in the critically ill patient, such as finding and treating a reversible cause for cardiac arrest, and *urgent* applications of POCUS in non-life-threatening conditions like identifying an abscess in a soft tissue infection and can change the course of treatment of a patient. In addition, a potential reduction of radiation exposure and/or reduction in time to diagnosis or disposition[5] could also be considered high yield. **Table 1** is a list of high yeild uses of POCUS in diagnostics and therapeutics that can readily inform and be performed by EMS and EM providers (**Table 1**).

CLINICAL SCENARIOS AIDED BY POINT-OF-CARE ULTRASOUND

When looking at the use of POCUS within clinical scenarios, the following applications of POCUS potentially have high-yield findings in clinical management:

- In *trauma*, the eFAST (extended Focused Assessment with Sonography in Trauma) as a diagnostic aid for potentially immediate life threats: tension pneumothorax, pericardial effusion with tamponade, and thoracic and intra-abdominal hemorrhage.[8] The full application and interpretation of results are taught in Advanced Trauma Life Support (ATLS) and will not be reiterated here.
- In *respiratory failure or distress and intubation*, POCUS can be used to evaluate for a misplaced esophageal tube[9] and potential iatrogenic or pathologic pneumothorax.[10] More nuanced findings of interstitial edema, consolidation, small pleural effusions, and pulmonary embolism might not be considered high yield because they can be difficult to interpret.
- In *cardiac arrest*, there are several reversible causes within advanced cardiac life support (ACLS) algorithms where POCUS[11–14] can aid identification and need for treatment including tension pneumothorax, pericardial tamponade, presence or absence of pulse, true pulseless electrical activity (PEA), ventricular fibrillation, and cardiac standstill. All will need to be supported by electrocardiogram and other findings.
- In *undifferentiated hypotension*, like the trauma patient with unstable vital signs, the presence of a pericardial effusion can inform decision-making. The rapid ultrasound in shock (RUSH) examination[15] has been proposed and shows high accuracy[16] for further evaluation of cardiogenic, hypovolemic, distributive, or obstructive shock. This examination requires training in obtaining and interpreting cardiac and central vascular findings.
- In *abdominal pain and hypotension*, the principles of the FAST (focused assessment with sonography for trauma) examination can be applied to look for free

Table 1
Summary of uses of point-of-care ultrasound

Examination	Probe	Easily Identified Findings	Potential Clinical Scenarios
Arterial Doppler	High-frequency linear probe with color Doppler at carotid, femoral, and radial artery	Confirm the presence of absence of pulses	CPR—confirm PEA or asystole Hypotension—identify cardiac activity without palpable pulse Ischemic limb—initiate early treatment or imaging
Lung Pleura	High-frequency linear probe with or without M-mode	Identify lung sliding and A-lines	Respiratory failure including CPR—rule out pneumothorax
Thorax	Low-frequency curvilinear or phased-array probe	Identify fluid in the pleural space	Blunt or penetrating trauma with unstable vital signs—indication for thoracostomy or thoracotomy tube for presumed intrathoracic bleeding
Cardiac	Low-frequency phased-array or curvilinear probe	Identify large pericardial effusion, confirm organized cardiac motion vs standstill vs ventricular fibrillation, distinguish between hyperdynamic vs poor ejection fraction	CPR—to identify a reversible cause of cardiac arrest or confirm cardiac standstill in PEA or asystole. Profound hypotension—help distinguish hypovolemia from other potential causes of heart failure
Abdomen	Low-frequency curvilinear or phased-array probe	Identify intraperitoneal free fluid (assumed to be blood in unstable patient)	Blunt or penetrating trauma with unstable vital signs—for prompt operative treatment intraperitoneal bleeding Unstable patient with possible ruptured ectopic, AAA, or abdominal aortic dissection
Pelvis	Low-frequency curvilinear or phased-array probe	Identify intraperitoneal free fluid, confirmation of urinary retention, and identification of IUP	Blunt or penetrating trauma with unstable vital signs—for prompt operative treatment intraperitoneal bleeding Unstable patient with possible ruptured ectopic, AAA, or abdominal aortic dissection

Abbreviations: CPR, cardiopulmonary resuscitation; PEA, pulseless electrical activity; AAA abdominal aortic aneurysm; IUP, intrauterine pregnancy

fluid that could represent intraperitoneal hemorrhage and necessitate emergent surgery and large-volume transfusion. Interpreting images of the abdominal aorta and uterus, if visualized, can help diagnoses aortic aneurysm or dissection and the presence or absence of an intrauterine pregnancy. These can readily be learned by the novice when good technique is used.

PREHOSPITAL APPLICATION OF POINT-OF-CARE ULTRASOUND

Several POCUS protocols have been proposed and are used by physician sonographers in the ED,[13,15,17,18] but the prehospital setting has unique challenges in an ever changing, noisy, and chaotic environment. One advantage of ultrasound is that it can provide visual information that can be seen and captured in a cost-effective manner outside the hospital. If applied in the appropriate circumstances with the right patient, by an adequately trained professional, ultrasonography can aid in diagnosis and treatment in the prehospital setting. The studies referenced and summarized in **Table 2** have proposed algorithms for the use of ultrasound in the prehospital setting.

Limitations of Prehospital Sonography

With the price of ultrasound units decreasing substantially as well as the availability of hand-held units, price and portability has become less limiting for EMS to purchase and use POCUS. While much more affordable, upkeep, maintenance, and troubleshooting need to be considered as recurring cost. Another cost to consider is staffing trained professionals and/or training prehospital providers in the appropriate use of ultrasound. Studies[12,13,21] have shown that training paramedics and implementing prehospital ultrasound protocols are feasible.

One potential disadvantage to introducing ultrasound to the prehospital setting is the possible inappropriate use of ultrasound that delays critical interventions. This was seen in studies showing in-hospital delays during pulse checks longer than 10 seconds during cardiopulmonary resuscitation (CPR).[22] Any delay in critical treatment for unnecessary diagnostic testing, including ultrasound verification of an obvious diagnosis, can be detrimental and should be avoided.

In addition, some findings such as massive intraperitoneal hemorrhage may not be able to be addressed outside of the hospital. A clinician caring for a critically ill patient must not "lose the forest for the tree" and become hyper-focused on a finding that may not warrant action at that time. Thus, clinicians must learn to incorporate POCUS into their evaluation and management of patients at the level of their training and in circumstances where ultrasound findings could change diagnosis or management of the patient.

APPLYING POINT-OF-CARE ULTRASOUND TO PRACTICE WITH PERTINENT CLINICAL QUESTIONS

A simplified and helpful approach to the use of ultrasound to make critical decisions and diagnoses is to use POCUS to answer binary (yes/no) pertinent clinical questions. These binary questions are well-suited for the PHC of patients. When posed as a yes or no question, it is plausible that less time would be spent "looking around" for other diagnoses that could delay care and may distract or confuse EMS providers.

Are Pulses Present?

Background: Recognition of the presence of pulses by palpation during CPR has been shown to be time-consuming and inaccurate in CPR trained providers.[23,24] POCUS used to detect pulses has been shown to be rapid,[23] more accurate,[25,26] and helpful in nonexpert sonographers to detect femoral pulses integrated into ACLS.[27]

Table 2
Summary of prehospital protocols integrating point-of-care ultrasound

Protocol	Study	Application	Pertinent Findings
FEEL[13]	Focused Echocardiographic Evaluation in Life support	Identify reversible causes[a] during CPR in cardiac arrest	Pericardial effusion, right heart strain, LV dysfunction, collapsing IVC, fine VF
US-CAB[12]	Ultrasound protocol for Circulation-Airway-Breathing	Sequential evaluation of circulation (heart and IVC), airway (trachea), and breathing (lungs)	Pericardial tamponade, collapsing IVC, esophageal intubation, lack of lung slide
CASA[19]	Cardiac Arrest Sonographic Assessment (CASA) examination: A standardized approach to the use of ultrasound in PEA	Three, < 10 s POCUS examinations that occur at pulse checks during CPR to identify reversible causes[a] of PEA	Cardiac tamponade, right heart strain, cardiac activity
PAUSE[20]	Prehospital Assessment with UltraSound for Emergencies (PAUSE) protocol	Pleura examination followed by focused TTE (subxiphoid, parasternal long views)	Assessment for pericardial effusion, pneumothorax, and the presence/absence of cardiac activity

[a] Reversible causes = pericardial tamponade, tension pneumothorax, pulmonary embolism, hypovolemia. CPR = cardiopulmonary resuscitation, LV = left ventricle, IVC = inferior vena cava, VF = ventricular fibrillation, PEA = pulseless electrical activity, TTE = transthoracic echocardiogram.

Pearls: A rapid assessment of carotid, femoral, or radial pulses can be performed during the pulse checks of CPR or in patients with undetectable BP.

Pitfalls: POCUS is highly accurate for the detection of pulses; therefore, false positives or false negatives would most likely be due to user error in obtaining and interpreting images. Users will need to understand how to operate their specific ultrasound machine with color Doppler and the fact that motion artifact can be confused for presence of a pulse.

Is There Organized Cardiac Motion?

Background: Similar to the use of POCUS for the detection of pulses during resuscitation within the Advanced Cardiac Life Support (ACLS) algorithm, POCUS has been proposed to be used to distinguish "true" Pulseless Electrical Activity (PEA) rhythm on electrocardiogram (ECG) with no cardiac activity from "false" PEA where organized heart motion may not result in palpable BP or adequate end-organ perfusion. Organized heart contractility can be easily recognized by the novice provider if adequate windows are obtained.

Pearls: This is another excellent adjunct to the physical examination during ACLS-guided resuscitation even with nonexpert sonographers.[27] PEA has an established treatment protocol, whereas profound hypotension with organized cardiac activity could be detected and treated appropriately.

Pitfalls: Echocardiography during CPR has been associated with prolonged delays during pulse checks.[22] Unfortunately, there was not good inter-rater reliability of physician interpretation of cardiac standstill,[28] and this finding alone is not an

accepted indication for termination of resuscitation. Prehospital workers should not consider a lack of organized cardiac movement as the sole reason to discontinue resuscitative efforts. A systematic review showed little evidence to support the use of a single decision rule in adult or pediatric patients to reliably predict mortality or survival with unfavorable neurologic outcome after in-hospital cardiac arrest.[14] Cardiac motion alone is not sufficient to terminate resuscitation.

Is There a Pericardial Effusion?

Background: One of the aims of the eFAST in ATLS is to identify immediate life threats that include pericardial effusion with tamponade. The absence of a pericardial effusion is valuable information in eliminating cardiac tamponade as an explanation for hypotension or shock. Prehospital providers may not be able to perform pericardiocentesis in the field, but the early identification might improve patient care once in the ED.

Pearls: In the context of hypotension, the absence of pericardial fluid essentially rules out cardiac tamponade as the cause and clinicians should look elsewhere. A large effusion found on POCUS, in the correct clinical context, can help inform the need for intervention with much better accuracy than auscultation and physical examination findings such as Beck's triad with greater speed than CT (computed tomography) imaging.

Pitfalls: It can be difficult to distinguish a pleural effusion from a pericardial effusion as well as a pericardial fat pad. In addition, large chronic effusions may not cause tamponade; thus, the user must understand and distinguish tamponade pathology in real time.

Is a Pneumothorax Potentially Present?

Background: Another aspect of the eFAST in ATLS is examining for the presence of pleural sliding at the apex of the chest where air is most likely to collect in a large, non-loculated pneumothorax. A tension pneumothorax is an immediate life threat in thoracic trauma. The presence of lung sliding bilaterally has a high probability of ruling out tension pneumothorax as an immediate life threat.[29] The absence of lung sliding does not mean that a tension pneumothorax is present, although in the unstable trauma patient with high enough suspicion, the benefits of prompt needle decompression might outweigh the potential risks. Outside of trauma, examination for pleural lung sliding can be applied in other circumstances such as suspicion of iatrogenic pneumothorax from mechanical ventilation or main stem bronchi intubation.

Pearls: Any provider with access to POCUS can learn to identify pleura sliding. Lung POCUS is faster than x-ray or CT imaging and has been shown to be more accurate than auscultation alone.[30] The sonographic setting M-mode can show a "seashore sign" pattern in normal pleural movement and "barcode sign" in pneumothorax.[31] The additional presence of A-lines improves accuracy.[10]

Pitfalls: False positives (lack of lung sliding) can be seen in patients who have had prior pleurodesis, and a large lung bleb also may not show reverberating A-lines. Both should be considered in clinical context and are relatively rare. User error by not selecting the appropriate depth or misinterpreting rib shadowing could also contribute to errors. Main stem bronchi intubation can lead to a lack of lung movement that could be misinterpreted as well.

Is the Endotracheal Tube in the Esophagus?

Background: During intubation, POCUS can be used to assess for successful intubation with accuracy similar to waveform capnography[32] and can be observed sooner than the few breaths it takes to obtain accurate capnography.

Pearls: This is an additional way to help detect a dislodged or inappropriately placed airway. POCUS performed well as a secondary measure to confirm endotracheal (ET) tube placement in pediatric patients as well.[33]

Pitfalls: The correct placement of an airway in the trachea seems essentially the same as a normal patient without an airway. Users are not "seeing" the tube in the trachea. Only tubes placed in the esophagus will be seen. Waveform and color capnography should continue to be used as the gold standard.

Is There Intrathoracic Hemorrhage?

Background: Because fluid is an optimal medium for sonographic detection, pleural effusions or hemorrhage should be easy to see so long as the user has experience with the appearance of normal lungs on ultrasound. In a breathing or ventilated patient, lung parenchyma may be visualized floating around within the surrounding fluid making pleural fluid easy to identify.

Pearls: In the trauma patient, a large collection of fluid could indicate intrathoracic hemorrhage that may prompt intervention such as a thoracostomy tube or open thoracostomy evacuation and examination for source.

Pitfalls: Identification of pleural fluid must be taken within the clinical context. Providers should understand if the finding has clinical significance to need immediate intervention or if an effusion is not likely to cause hemodynamic instability or respiratory failure.

Is There Intra-abdominal Hemorrhage?

Background: The FAST examination was designed to look for free fluid in the abdomen as an indicator of intra-abdominal hemorrhage, and in the unstable patient with no other obvious source of hemodynamic instability, prompt immediate surgical exploration without the delay of CT confirmation. It has, however, performed very poorly in ruling out intra-abdominal injury and cannot detect retroperitoneal hemorrhage, bowel injury, or diaphragmatic injury. Thus, it should always be used to aid in decision-making to proceed to the operating room when positive. Outside of trauma, the same technique can be used looking for free fluid as a sign of intra-abdominal hemorrhage in cases with suspicion of ruptured ectopic pregnancy or vascular catastrophe like a rupture abdominal aortic aneurysm (AAA). The overarching principle of not delaying surgical intervention if free fluid is found, while understanding that intra-abdominal injury or hemorrhage is not ruled out by a negative abdominal POCUS examination, is paramount.

Pearls: The FAST examination includes trauma in the name, but this protocol can be applied in cases with suspicion for nontraumatic intraperitoneal bleeding. This should be in the skillset of any clinician expected to care for trauma patients, thus its inclusion in ATLS, but is valuable beyond trauma in the hemodynamically unstable patient with possible intra-abdominal hemorrhage, thus should be learned by all EM providers.

Pitfalls: The FAST is not sensitive at ruling out intra-abdominal pathology and thus should never be reassuring when negative except to say the patient does not meet criteria for immediate operative management. In the hemodynamically unstable patient without obvious source, intraperitoneal bleeding should remain on the differential diagnosis even with a negative FAST.

SUMMARY

The use of ultrasound in the emergency room and prehospital setting can offer many ways to improve diagnosis and treatment of critically ill patients when used to answer

specific clinical questions with easily identified POCUS findings that are pertinent to immediate patient care.

CLINICS CARE POINTS

- Point of care ultrasound (POCUS) can be a very useful tool for immediate diagnosis of life-threatening disease in the hospital and prehospital setting.
- It has been shown that with proper training physicians and physician extenders can learn to identify sonographic findings that can change diagnosis and treatment.
- POCUS has also been shown to delay critical interventions, such as high-quality chest compression, thus should be used judiciously and within proper clinical context.
- Small studies have shown some success in implementation of prehospital sonography protocols.
- Currently, the best application of POCUS in the critically ill patient is the previously well-established incorporation into Advanced Trauma Life Support (ATLS) and the use of POCUS to answer binary (yes/no) questions that may change the diagnosis and immediate treatment of patients. These include more accurate identification of the presence of pulses, pericardial effusion, organized cardiac motion, pneumothorax, endotracheal tube in the esophagus, and intra-thoracic and intra-abdominal free fluid.

DISCLOSURE

Nothing to disclose.

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