It’s Time to Embrace Point-of-Care Ultrasound
A young woman presents to Necker hospital in Paris, France, with symptoms that suggest possible cardiac disease. The year is 1816. The patient is assessed by Dr. Rene Laennec. Physical assessment and percussion of the chest reveal little about her condition. Given the patient’s age and sex, immediate auscultation (placing the ear directly on the chest to auscultate heart tones) is barred by social standards. The good doctor is at an impasse.

Earlier that year Laennec witnessed two schoolchildren playing with a long piece of wood and a pin. One child would put the wood against his ear, while the other scratched the far end of the wood with the pin. The sound transmitted through the wood, allowing the first child to hear it.

Recalling that, Laennec rolls a piece of paper into a tube, places it against the patient’s chest wall and listens through the opposite end. As he suspected, he can hear the patient’s heart tones with greater clarity than even immediate auscultation allows.

Following this discovery, Laennec experiment with different materials and develops a hollow wooden tube, approximately 1.5” in diameter and 10” long, which allows quality auscultation of the chest. He calls it the stethoscope, borrowing the Greek stethos (chest) and skopos (examination). He presents his findings in 1818, and the New England Journal of Medicine publishes them in 1821.

Expanding the Diagnostic Arsenal
Laennec’s stethoscope was made obsolete in 1851 by Arthur Leared, who invented the first binaural stethoscope. Leared’s design was further improved a year later by George Cammann and soon went into commercial production. A comparison of Cammann’s stethoscope and the modern variety reveals few differences. Today this 160-year-old device is still the most used piece of equipment in our limited diagnostic arsenal—clearly a testament to the genius of the design. But has the stethoscope outlived its utility? Should we look beyond it? Are there newer diagnostic tools we need to consider?

As we transition from technicians to clinicians and begin to embrace evidence-based medicine over anecdote and tradition (I’m looking at...
you, backboards), it is important to take a good, hard look at our tools and capabilities. Perhaps the most important aspect to evaluate is our diagnostic capabilities. If we cannot identify and diagnose (yes, we do) a patient’s pathology with a reasonable degree of accuracy, we cannot effectively treat them and may even cause greater harm.

While our monitors provide accurate, objective, quantitative data, the same cannot be said of our stethoscopes or senses. How many times have you found yourself trying to determine if you’re hearing rhonchi or rales? Or simply determine whether you heard breath sounds on the affected side of a possible pneumothorax? Or trying to determine if the endotracheal tube migrated to the patient’s right main bronchus while in flight? Or whether you actually felt a pulse during a pause in CPR?

One study found that only 45% of prehospital providers were able to accurately identify a carotid pulse and terminate CPR.1 Another demonstrated that of a cohort of EMTs and paramedics, only 15% were able to correctly diagnose the presence or absence of a carotid pulse within 10 seconds.2 Subjective measurements are notoriously unreliable and can harm our patients. This is a concern that desperately needs to be addressed. Fortunately, a portable technology already exists that allows us to evaluate a patient’s status at a much deeper level: point-of-care ultrasound.

The first documented use of ultrasound in a diagnostic capacity was in 1942, when Karl Dussik attempted to visualize brain tumors. The field of echocardiography was established in the 1950s. The release of the first real-time ultrasound scanner came in 1965—previous machines only produced single still images. These early ultrasound machines were enormous, clunky devices, and some even required the patient to be submerged in a tank of water.

As with the evolution of computers, ultrasound machines have become smaller and faster as technology improves. Many modern point-of-care ultrasound units are around the same size as a laptop computer and are built with a similar form factor, while some even smaller units are available, including tablet-style units and even transducers that simply connect to a user’s existing smartphone or tablet with a cable or even wirelessly via Wi-Fi direct.3-5 With such an available variety of sizes and form factors, the technology can be incorporated into any environment, whether a large ambulance, a small single-engine helicopter or even a confined-space or collapse scenario.

Prehospital Adoption

Thus far, the adoption of ultrasound in the prehospital arena has been mostly unsuccessful. While several services in the United States have trialed it, it has often been relegated to performing the FAST (focused assessment with sonography in trauma) exam. In theory it would be used as a triage tool, potentially altering transport decisions and possibly expediting surgical intervention on the patient’s arrival at the hospital. Without a close relationship with trauma facilities, the exam fails to show much utility. Understandably, few surgeons are willing to trust the judgment of a prehospital provider to the point of performing surgery without first confirming the findings themselves.

Additionally, using the FAST exam to make transport decisions is a dangerous and fallacious concept. A relatively large amount of free fluid needs to be present to create a positive scan. One study utilizing a cohort of physicians showed that fewer than 10% were able to identify a positive scan of Morrison’s pouch with less than 400 mL of fluid present; the mean amount of fluid needed for detection was over 600 mL.7 More recent data shows an improvement, with experts being able to detect 100–200 mL of fluid, but this is highly dependent on the skill and experience of the provider.

This means the sensitivity of the FAST exam is relatively low—somewhere in the neighborhood of 73%–88%, meaning that up to a quarter of FAST “negative” patients in fact do have intra-abdominal bleeding which may still need immediate surgical intervention.8 The FAST exam rules in bleeding; it does not rule it out. It is questionable if a negative FAST exam should even be considered “negative.” It may be safer for our patients to refer to it as “inconclusive.”

Even ignoring these issues, purchasing equipment and investing in training providers for a single triage exam is hard to justify from a budget perspective, no matter how sensitive or specific it may be. It is time we forget our preconceived notions and reevaluate the potential of sonography in the prehospital arena with a clean slate, an open mind and from an evidence-based perspective.

That being said, the FAST exam has proven to be little more than a distraction from the full potential of point-of-care ultrasound (POCUS) in the prehospital environment. Many providers (myself included) have mused about the day when we may have a portable x-ray machine in our ambulances. The truth is that we’ve been unknowingly ignoring technology that is not only already available but superior to x-rays in many ways—both in safety, as the patient is not exposed to ionizing radiation, as well sensitivity in many applications. We are notoriously averse to adopting new treatments and knowledge that “won’t affect my care.” Ultrasound will absolutely affect the care we provide prehospitally and improve outcomes. As of today, potential indications for POCUS include cardiac complaints, cardiac arrest, respiratory distress, trauma, shock, head injuries, vascular access, nerve blocks for analgesia and more. In the near future, we may use it to both diagnose and treat ischemic stroke.9,10 Looking at the longer term, prehospital POCUS may bring more advanced interventions into the field, such as nerve blocks and the insertion...
A normal heart bordered by the bright white pericardium.

Pericardial tamponade with fluid between the heart and pericardium.

of arterial lines to help guide resuscitation. It could even open the doors to eventually preparing patients for extracorporeal membrane oxygenation (ECMO) upon arrival at the emergency department or assisting a physician responder in crashing a patient onto ECMO in the field, which has been proven to be feasible and safe by the SAMU program in Paris—which, coincidentally, is based out of the same Necker hospital where Laennec practiced.11

A recent systematic review of prehospital ultrasound literature shows that of the cases in which ultrasound was utilized in the field, patient treatment was changed as a direct result of sonographic findings in 21%–30% of cases.12

**How Does POCUS Work?**

To perform an exam, a transducer, or probe, is placed against a patient’s skin. The transducer emits high-frequency sound waves, above the human range of hearing (ultrasound), for a fraction of a second. After transmitting the sound waves, the transducer then “listens” for an echo. Different materials, typically tissue in our case, absorb and reflect sound waves differently and affect the echo signal. Two concepts of physics are responsible for this: **acoustic impedance and attenuation.**

Impedance is a measure of the resistance of a material to the penetration of sound waves. A high-impedance tissue reflects the majority of sound energy. A less abstract example: Imagine throwing a ball at a brick wall. The ball travels easily through the air because the air has low impedance. When the ball hits the wall, it suddenly stops and is reflected, due to the high impedance of the wall.

When sound waves transition between materials with a large gradient of impedance levels, they scatter unpredictably, severely hampering the echo and creating a signal that’s unable to be processed into a useful image. Air has an infinitesimal impedance compared to all other materials. This phenomenon is why ultrasound gel or other fluid is required: The gel creates an airtight seal with the patient’s skin, lessening the impedance gradient.

Related to impedance is attenuation, the loss of energy from sound waves being absorbed and deflected. The lower a tissue’s impedance, the less energy is lost as the sound waves pass through it, allowing them to travel further into the body. Looking back at the ball/wall analogy, the brick wall’s high impedance severely attenuates the ball’s forward kinetic energy—little or no energy would be detectable on the opposite side of the wall. If the same ball were thrown at a wall made of tissue paper, the ball may be able to pass through it but will still experience some amount of attenuation and lose kinetic energy due to the wall’s impedance.

Materials that absorb the vast majority of sound energy while reflecting very little, such as fluid (including blood), are considered **anechoic** (without echo). Conversely, materials that reflect a large amount of energy (e.g., bone) are **hyperechoic** (an exaggerated echo). These properties affect the echo the transducer receives.

Once the echo is received by the transducer, the signal is interpreted into a visible image, with varying shades of grey representing the interaction of the sound waves with tissues. Anechoic tissue is black, and hyperechoic is white, with everything in between.

Transducers are available in many sizes and shapes. Size and shape are important when considering what part of the body is to be examined. For example, when looking into the thoracic cavity, a transducer with a smaller face is preferred in order to project sound waves through a single intercostal space. As you recall, bone lets very little sound energy pass through it, so nothing will be visible directly behind the ribs.

Another less obvious difference in transducers is the frequency at which they operate. Each transducer has a certain frequency range it is able to utilize. The lower the frequency, the further it will penetrate through tissues. Higher frequencies are more easily absorbed, giving them low penetrance but producing a higher-resolution image. Think about hearing loud music from a distance: The bass line will be heard from farther away than the vocals, as the low-frequency energy travels farther.

To view shallow structures such as peripheral vasculature, the periphery of the lungs and the globe of the eye, a high-frequency linear transducer is used with a range around 13–6 mHz. In order to see farther into the body, such as into the thorax or abdomen, a lower frequency is required. A phased array transducer (with a range in the area of 5–1 mHz) can be utilized to examine both the thoracic and abdominal cavities. A curvilinear array operates in nearly the same range as a phased array and is preferred by some for abdominal exams, due to its larger face and curved shape. However, it cannot be used effectively for cardiac imaging, as it will not fit between the patient’s ribs.

Transducers make up a large part of the cost involved in obtaining an ultrasound unit—each costs $2,000–$5,000, depending on type and manufacturer. While the combination of linear, phased array and curvilinear array may be optimal, all the use cases we will be looking at can be successfully performed with just the linear and phased array transducers, reducing the adoption cost for services interested in ultrasound.

Though some devices’ appearances can be intimidating, featuring full keyboards with a large number control keys, most of these are unnecessary for our uses. The basic controls of an ultrasound unit are quite simple. **Gain** makes the image on screen darker or lighter, allowing adjustments to better visualize structures. **Depth** changes how far the ultrasound waves travel into the body by regulating the frequency emitted. Keep in mind, just as when comparing different transducers, the same give-and-take applies: The deeper you look, the lower the resolution of the image. As the depth is adjusted, the scale on the side of the screen changes, allowing for quick estimation of how far into the body an area of interest lies.

Multiple **modes** are available with modern ultrasound machines. The “standard” mode that comes to mind when you imagine what an ultrasound image looks like is **two-dimensional (2D)** mode. Images are simply created based on the echogenicity of structures. The mode is also...
Prehospital Ultrasound In Action

An increased optic nerve sheath diameter has been shown to act as a surrogate for increased intracranial pressure, allowing for noninvasive monitoring of ICP and may guide treatment.

Qualitatively estimate ejection fraction to determine need for inotropic support, differentiate PEA vs pseudo-PEA, identify pericardial tamponade and guide pericardiocentesis.

Estimate circulating volume status by visualizing the inferior vena cava to determine need for fluid resuscitation.

Identify aortic aneurysm and dissection.

Can reveal occlusions of the middle cerebral artery (MCA), which is responsible for over 50% of ischemic strokes. There is some evidence that externally applied ultrasound waves may be able to break down clots at the cellular level, allowing for treatment in the field without dangerous fibrinolytics.

Can identify multiple pathologies, including bronchial intubation, pulmonary edema, pneumothorax, pneumonia, atelectasis and pleural effusion.

Identify internal hemorrhage from traumatic and medical (e.g., ruptures of ectopic pregnancy or aortic aneurysm) causes.

Rapidly guide vascular access in difficult populations, such as pediatric, shocked or obese patients.

Nerve blocks for safe treatment of extreme pain from fractures or extrication.

Femoral artery cannulation for monitoring and titrating resuscitative treatments. Future utility for REBOA and ECMO.

DEMONSTRATION
Visit the EMS World Expo Sim Lab for a presentation by Branden Miesemer and Jason Boitnott on ultrasound in prehospital care.
Case Study: Implementing POCUS

By Howard K. Mell, MD, MPH, CPE, FACEP

In July 2015, I became the EMS medical director for the Iredell County (NC) EMS service. Working with the service’s director, Blair Richey, and assistant director, Ryan Wilmeth, we performed a needs analysis to identify any areas of opportunity to better serve the citizens of our county. As a result of that analysis, Iredell County EMS is in the midst of a complete overhaul of its trauma protocols. These changes, and early outcomes from our efforts, will be discussed at EMS World Expo in New Orleans, LA, October 3–7.

A cornerstone of these new protocols is the introduction of point-of-care ultrasound (POCUS) to our EMS units. Three ultrasounds have been deployed with EMS supervisors and one is held in reserve by the training division. Each machine has linear and phased array probes.

We chose the Terason uSmart 3200T for a number of reasons. The units are extremely portable, being the size of a large tablet computer, and are surrounded by a large rubberized case for durability. They are full-function units, capable of accepting a variety of probes, allowing providers to eventually increase the use of POCUS into newer and more varied indications. They have a touch screen and a very intuitive user interface. The units have a Windows-based architecture, which can be updated remotely via WiFi. Additionally, the solid state hard drives on the machines make preserving images for review—both in real time on patient arrival in the ED and later for QA—a breeze. Lastly, the support Terason has provided in terms of training has been nothing short of incredible.

We currently use ultrasound in three roles:

» For the traumatically injured patient, we perform an extended focused assessment with sonography for trauma (eFAST) exam. The results of the study, either indeterminate or positive, are radiated to the receiving trauma center. While the result may not directly change our care of the patient, the positive eFAST exam functions like a positive 12-lead ECG in ST-elevation myocardial infarctions: The information allows the receiving center to better prepare to rapidly treat the patient.

» Our second POCUS indication is to assess for the presence of pregnancy in obtunded trauma patients. Again, the idea is to provide the receiving facility as much information as possible so the patient’s needs can be rapidly met.

» Our third POCUS study is to assess cardiac motion to guide cardiopulmonary resuscitation efforts in both traumatic and medical cardiac arrest scenarios.

A group of senior paramedics and paramedic supervisors underwent 12 hours of training, both in classroom and with live models, in the performance of the POCUS studies above.

At the end of training, a 50-image test, with 10 “positive” studies hidden among 40 “normal” pictures/video clips, was administered. With one positive image thrown out of the test because of poor inter-rater agreement among the instructor cadre, every member of the class scored 91% or better.

Case Study: Implementing POCUS

Use for trauma in the field thus far has yielded three positive studies (one hemoperitoneum and two spontaneous pneumothoraces), each later confirmed in the ED. One potential “miss” (defined as a positive eFAST in the trauma center not detected by EMS) was also identified during QA/QA. We are moving forward with plans to expand POCUS use into our active shooter triage protocols, to aid in establishing peripheral IV access, and into our care of the non-traumatic patient who is in shock of undetermined origin. Overall we consider the project a resounding success and look forward to the future and expanding our use of POCUS in prehospital care.

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commonly referred to as $B$-mode, for brightness, as structures are displayed at varying levels of brightness depending on their echogenicity.

$M$-mode is used to display information regarding movement. A B-mode image is shown with a vertical line through it. When M-mode is activated, a graphic appears on the screen, reflecting movement seen along the vertical line. This is useful to evaluate the movement of structures, such as cardiac valves or the sliding of the visceral pleura against the parietal pleura during ventilation.

Multiple Doppler modes exist, and depending on the unit, several may be available. Just like the Doppler radar you may be familiar with shows the movement of weather systems, ultrasound Doppler modes show movement. While M-mode detects the movement of structures, Doppler detects fluid flow—in this case, blood. The most common Doppler mode is color Doppler. In this mode, flow toward the probe surface is shown as red on the screen, while flow away from it is displayed as blue. It is important to remember that unlike textbooks, red and blue do not necessarily correlate to venous and arterial flow; it depends on the probe’s orientation. This mode may be used to aid in quickly identifying vasculature for cannulation and can even reveal occult cardiac problems, including valvular regurgitation or congenital structural problems, such as a patent foramen ovale or atrial septal defect.

Interpretation

Many providers may be hesitant when considering integrating sonography into their practice due to their (completely valid) concerns of competency in correctly interpreting images. One thing that must be kept in mind is that we are not performing advanced exams, such as full cardiac evaluations to look at in-depth valve function or calculating a precise ejection fraction. Generally speaking, a prehospital POCUS exam should answer a simple “yes or no” question: Are the lungs inflated? Is there fluid present in the pericardium? Is the heart contracting normally?

While exams providing more advanced calculations could be performed in the field with sufficient training, the greatest return on educational investment lies in these simpler exams, which still provide diagnostic information that would be impossible to obtain otherwise, at least to the same accuracy. With sufficient training, information from these exams will be available as important evidence when narrowing down a differential diagnosis. It is important to recognize that this is only a single part of the patient care puzzle. The full clinical picture must be considered.

Photo by Ryan Wilmeth
Consider the 12-lead ECG: An expert can gather an enormous amount of information from a typical 12-lead to aid in diagnoses such as electrolyte derangements, congenital abnormalities or pulmonary hypertension. However, most EMS providers are given a very brief overview of ECGs, mostly in determining whether a STEMI is present. While there is a great amount of potential that typically goes unused in our environment, very few would argue that being able to diagnose STEMI in the field has had an enormous positive effect on the populations we serve, even though we may not all recognize cor pulmonale or an enlarged right atrium. When looking at any potential diagnostic tool for use by providers of any level, it’s important to look at the benefits of realistic use, and not forgo “good” simply because we may not be able to achieve “perfect” on a wide scale.

That being said, training and its associated costs are an important factor for a service considering adopting ultrasound. It would be reasonable to assume introducing an entirely new concept would take many hours of training; however, multiple studies have been performed to evaluate training requirements for new paramedic operators of ultrasound, and it has been shown that competency can be attained in a relatively short period of time, depending on the exam type.

One trial showed that after a 10-minute lecture, a cohort of 33 paramedics was able to correctly identify the presence of pneumothorax on 20 prerecorded video clips (10 of which were positive for pneumothorax and 10 normal) with a sensitivity of 82% and a specificity of 94%. To offer some context, a 2014 meta-analysis of 28 studies compared the diagnostic value of supine chest x-rays to thoracic ultrasound, both interpreted by physicians in the hospital environment. The overall sensitivity and specificity of x-ray imaging was calculated to be 46% and 100%, respectively. Thoracic ultrasound was found to be 87% sensitive and 88.9% specific. Based on the above, the test group of paramedics was able to correctly detect pneumothoraces at a higher rate than physicians using chest x-rays, and at nearly the same rate as physicians who also utilized ultrasound, after only 10 minutes of didactic training.

Similar success was seen in a 2008 prospective, observational study in the field. Forty paramedics in two Minnesota 9-1-1 systems volunteered to undergo an initial six-hour training on the FAST and abdominal aorta (AA) exams. This education was supplemented with two one-hour refresher sessions at around the third and eighth months of the trial period. The paramedics also had access to training videos on both exams available on demand. A total of 104 patients were scanned during the period (84 FAST, 20 AA), with six-second video clips of each view recorded. A blinded emergency physician with over 15 years of ultrasound experience at a major academic center provided an overview of each of these exams and agreed with 100% of the paramedics’ interpretations.

Naturally, the more exams and indications that will be utilized, the higher the training requirements will be. It’s not unreasonable to consider a strategy of adopting sonography for a small number of high-yield exams initially and expanding its role as time goes on and providers become more comfortable. A strong argument can be made for integrating ultrasound education into paramedic classes as soon as possible, in order to start building a population of paramedics who are comfortable and competent with the technology. As an extra benefit, ultrasound can be used as an adjunct in the classroom for teaching anatomy and physiology, allowing students to see, for example, how structures fit together and how the heart functions.

One more big fear in adopting any drastic new diagnostic or therapeutic device is legal liability. The same concerns are held by many emergency physicians, even though point-of-care ultrasound is rapidly becoming the standard of care. A 2012 study of litigation involving point-of-care ultrasound in the ED over a 20-year period found that only one emergency physician was sued—for failing to perform an exam to diagnose an ectopic pregnancy. A five-year review published in 2014 found five lawsuits filed against emergency physicians—again, all for failure to perform an exam included in the ACEP list of core ultrasound applications. Interestingly, two of the cases involved pulmonary emboli in young patients—a teenage female and 8-year-old male. The rapid and simple nature of point-of-care ultrasound may make more thorough assessments possible, allowing providers to more frequently uncover conditions considered unlikely for a particular patient.

**Final Considerations**

Despite the potential for prehospital ultrasound, it is not a silver bullet. Just like any other diagnostic, it is only a tool and simply gives the provider extra data to consider. Critical thinking is still critical.

Ultrasound does not discount the need for a proper physical exam; rather, it augments it. Most of us know that despite what textbooks may imply, the sensitivity of many exam findings is extremely low—for example, tracheal deviation in tension pneumothorax or Beck’s triad in cardiac tamponade. Incidentally, both of these conditions are extremely easy to diagnose in seconds with ultrasound. Having this imaging capability will allow providers to fill in the holes the physical exam may leave without resorting to guessing and playing the odds.

It is clear that point-of-care ultrasound is the gateway that we as a profession must pass through in order to continue to improve the care we give. Over the next few months in EMS World Magazine, we will take an in-depth look at how ultrasound will allow us to uncover and treat life-threatening conditions that would otherwise go unnoticed.

References available online at EMSWorld.com/12231975.

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