6 Ultrasound in Combat Trauma

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Deployment Experience

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> *"Failure to immediately recognize and treat simple life-threatening injuries is the tragedy of trauma, not the inability*
> *to handle the catastrophic or complicated injury."*
>
> *F. William Blaisdell*

BLUF Box (Bottom Line Up Front)

1. Never delay transport to the OR for *any* radiologic study in an unstable patient with clear indications for immediate operative intervention. However, US can give quick and useful data in patients who are foregoing CT scan en route to the OR.

(continued)

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2. US is much more sensitive than supine CXR for the detection of pneumothorax and hemothorax in blunt/penetrating trauma in experienced hands, and US should not be delayed for plain radiography in most situations.
3. US should be performed after the ABCs have been addressed: think "ABC-U."
4. Serial EFAST examinations add to the sensitivity of the test. Do an initial EFAST on arrival, and repeat the exam in 60–90 min, or if the patient's status changes. Hemoperitoneum and hemothorax may take time to accumulate.
5. US is operator-dependent, so always consider the skill and experience of the US operator and his/her confidence level when interpreting US findings.
6. Injuries on today's battlefield often include varying combinations of burns, penetrating trauma, and blunt trauma. In severely burned patients, the EFAST can quickly identify or rule out other life-threatening injuries as you aggressively manage the patient's thermal wounds.
7. US can give vital information that providers can use in making immediate triage decisions, particularly in the setting of multiple unstable or potentially unsalvageable trauma patients.
8. Use "down time" during your deployments to get comfortable (or proficient!) with US.

Why Ultrasound?

Ultrasonography as a tool in wartime trauma management first gained widespread use during the First Gulf War, and its use has grown substantially over the past decade and a half of conflict. While most recently graduated surgeons and emergency physicians seem to embrace this modality, it can be challenging for providers who did not receive US training in their residency. Most are familiar with US, but lack the training and hands-on experience to really apply it at the bedside. That's the rub; not only does the trauma doctor need to know how to interpret and act on US images, he/she must also learn the skill of obtaining usable images *in an acceptable amount of time*.

This brief chapter is not designed to take the place of proper US training or an US course, but rather to give an overview and some references/reminders for US applications. Despite feeling comfortable or even competent performing US, true proficiency will only come through performance of dozens of extended trauma ultrasound exams. Furthermore, these skills will degrade if not practiced continually. There is a big difference between thinking a patient probably has a pneumothorax on US and actually knowing it exists (*and* placing a chest tube based on your US findings without obtaining other radiologic studies). If you are a deploying surgeon or physician who will be managing any type of combat casualties, then you *must* become familiar with the basics of ultrasound and the standard trauma exams (focused assessment with sonography for trauma or FAST) *before* you deploy.

With very little additional time and effort, you can add the skill set of basic thoracic imaging to perform the extended FAST exam (EFAST).

The great news is that most of us will be deployed with easy access to an ultrasound machine, and deployment is the perfect time to refine/maintain our US competency. Tap into the US expertise of skilled ultrasonographers in your unit – be it the radiologist, emergency physician, or trauma surgeon. Apply the skills you know and practice repeatedly on your medics or EMT patients until you feel very comfortable with the probe positioning and the images you obtain. If time allows, as you refine your skills, go back to the stable trauma patient who has already had a positive CT finding and perform a US. Alternatively, bring the machine to the ICU and perform exams on patients with known intraperitoneal fluid (usually postop) or cardiac effusions. Recognizing positive findings and learning how intraperitoneal blood, pericardial blood/fluid, or intrathoracic blood/air looks on US is a critical part of attaining proficiency. Most of us won't attain proficiency until we have performed and interpreted numerous positive EFAST scans, in addition to our "training" scans on normal patients. Once you have developed the basic skills of image acquisition, start working on efficiency. If you cannot do this quickly in a trauma resuscitation, team members can get annoyed and the slow ultrasonographer usually gets pushed out of the way. You must be able to obtain the information both accurately *and* efficiently, or this modality isn't very helpful.

Before you deploy, make certain that your unit will have at least one functioning US machine, or have your unit purchase one. If deploying with a CSH, get your command and supply personnel to help purchase multiple machines. US machines in the CSH will likely be in constant demand from intensivists, radiologists, and other providers. There will be times when you need an US for the evaluation of a critical patient, but they may be tied up in other parts of the hospital. Think about this in advance, since it can be very hard to get additional or upgraded US units in theater. Also have your supply folks consider the wear and tear, and coordinate with the manufacturers for replacement parts and repair ahead of time.

Advantages of US

1. Essentially replaces diagnostic peritoneal lavage (DPL) for the detection of hemoperitoneum (quicker, noninvasive, less complications) in most scenarios.
2. Tells you if there is significant blood in the abdomen, chest, or pericardium, allowing you to more quickly perform necessary interventions (including exploratory laparotomy or emergent thoracotomy).
3. Identifies pneumothorax quickly and easily. This is very useful in managing patients in the field, or at a role I or II facility where US is the only available radiologic modality.
4. Shows us what is happening at a given point and time and allows for trending. Serial EFAST scans (after rolling the patient or after placing them in Trendelenburg position) increases the sensitivity in the stable patient.

5. Can be done quickly and at bedside; no need to send unstable patients to the “black hole” of radiology; gives additional, immediate data in patients being taken straight to the OR.
6. No contrast or radiation exposure.
7. Easily moved from patient to patient, allowing rapid triage in a MASCAL setting.

Disadvantages of US (for the Average Ultrasonographer)

1. May miss small hemoperitoneum (100–200 ml detectable in pelvis view, 250–500 ml detectable in hepatorenal view).
2. Does not normally identify the *site* of intra-abdominal bleeding
3. Does not show hollow viscus injuries well.
4. Does not reliably show retroperitoneal bleeding.
5. Does not tell us if free fluid present is blood, ascites, urine, or (in chest) pleural effusion.
6. Relatively insensitive in pediatric patients (although helpful if positive).
7. Can be difficult to perform US in certain patients due to body habitus, air, etc.

How to Perform an EFAST

The EFAST (Extended Focused Assessment with Sonography for Trauma) is the basic US exam used to evaluate thoracoabdominal injury. There are four basic views that are traditionally obtained in the FAST exam: right upper quadrant (RUQ), left upper quadrant (LUQ), pericardium, and pelvic. The “E” or extended portion of the EFAST came about after thorax scanning for pneumothorax was added later. Evaluation for hemothorax is more commonly being performed as part of the FAST. Search for blood above the diaphragms as you do the RUQ/LUQ abdominal views. Below is an explanation of basic techniques for obtaining views. Realize, however, that the EFAST is a dynamic process, not a series of 4–6 images. Slide the probe around and look at each view from different angles to increase your sensitivity. Placing the patient in Trendelenburg position may increase the sensitivity of your RUQ view if you are unsure if there is fluid on the pelvic view. Also, recall that a negative EFAST, particularly early in the evaluation, might still be missing accumulating blood in the intraperitoneal or thoracic space and that results should not be used in isolation when managing a trauma patient. EFAST should be repeated in certain clinical settings if initially negative. We should view US as a dynamic process and interpret results in light of the patient’s clinical picture and stability. Free intraperitoneal or intrathoracic fluid (unlike fluid within organs) tends to form collections with sharp edges or triangles as it settles between structures, rather than rounded edges seen within a viscus. Free fluid will also change size with patient repositioning and accumulation or drainage of fluid from that space.

Basic Terms, Knobology, and Probe Selection

Not to get too technical, but we need to use certain terms to communicate in US lingo. Basically, an US probe (transducer) pushes out acoustic waves and detects reflected waves (from dense matter) that bounce back to the US probe. US waves that pass through homogenous materials do not reflect back to the probe and are termed *anechoic* (completely black, implies homogenous fluid such as urine, unclotted blood, or water). Most other organs and structures in the body are represented in shades of gray (or degrees of echogenicity), as sound waves pass through them with varying degrees of reflection back toward the probe. The more *hypoechoic* the structure, the more fluid filled and homogenous they are (and the darker they appear on US). *Hyperechoic tissue* is generally more dense and reflective (higher impedance, like bone), showing up white or lighter-gray on US. Isoechoic means that the adjacent tissue has similar appearance (or echogenicity) due to similar degrees of impedance. Examples of varying degrees of echogenicity from darker to lighter (anechoic to hyperechoic) are water-fat-liver-tendon-bone. Remember that air is the sonographer's enemy; sound waves transmit poorly through air (due to scatter) in comparison to fluids and solid organs and thus limits our exams when present. Large amounts of air in the intestine can render an abdominal US meaningless if we cannot navigate around it. Conversely, echodense structures such as the liver provide excellent sound wave transmission and can serve as a window to examine deeper structures.

The knobs on the US machine vary greatly depending on the make/model of the machine, so get to know your machine so you can tell which knob does what. The most important knob (other than the power switch) is the gain. *Gain* is basically how much amplification comes from the transducer. The more you turn it up, the more white all structures will appear on the screen. Inappropriate gain can make interpretation difficult, so adjust the gain until images look "about right" (yes, this is subjective and the more scans you do, the better idea you will have of what your images should look like). The other important knob to find is the depth. Adjust the *depth* knob to ensure the area you are imaging fits in the middle of the screen and isn't too deep (image of interest appears small at the top of the screen – hard to see details) or too shallow (area of interest extends beyond bottom of screen). There are usually markers on the side of the image that give a scale in centimeters for depth. A normal starting depth for the abdominal portion of the EFAST is in the 12–19 cm range. The other buttons can be useful in some situations, but not mandatory for doing a basic EFAST exam.

Probes come in different sizes, shapes, and design (Fig. 6.1). There is a basic trade-off to be considered when selecting a probe – the higher the frequency, the better the resolution and image quality, but the less penetration you get. Conversely, lower-frequency probes have greater penetration, but the images have lower resolution. Most EFAST views should be performed using low-frequency probes (2–5 MHz), while the high-frequency probes (5–10 MHz) are great for pneumothorax studies and superficial applications (soft tissue, vascular access). A high-frequency probe is best for pneumothorax scans, but the abdominal/low-frequency probe can

Fig. 6.1 Examples of different types of US probes. The probe to the left of the image is a linear (higher frequency) transducer useful for superficial applications and lung imaging. The probe in the center is a phased-array transducer useful for cardiac and deep "between-rib" applications. The probe to the right of the image is a curvilinear (lower-frequency) transducer useful for deeper (intra-abdominal) applications

also be utilized. A smaller footprint, phased-array transducer (looks like a square box) can be used to allow imaging between ribs without interference for the EFAST views, although some prefer the larger, curve-shaped, low-frequency abdominal probe because of better image quality. All probes have a *transducer indicator* for orientation; the image on the US screen has a colored dot that correlates with the end of the transducer that has the marker. The general convention is to orient the indicator toward the patient's right side (for transverse/axial imaging), or toward the patient's head (for sagittal and coronal imaging).

It helps to be familiar with the characteristics of each probe, and choose the one with which you feel most comfortable when performing an application. As an aside, make sure the trauma team members know how to clean the probes and to keep them off the ground and secured when moving the unit. A damaged probe can cost tens of thousands of dollars (and weeks of repair) if the cord is run over or the probe is dropped.

RUQ (Perihepatic or Hepatorenal) View

Opinions vary, but this is probably the view you want to obtain first in *blunt* trauma, as solid organ injury causing hemoperitoneum/hemothorax are more likely. Free intraperitoneal blood is most often identified in Morison's pouch, between the liver and right kidney. This is a relatively easy site to see abnormalities in, even for the novice sonographer. This view reliably detects volumes of about 600–700 ml of blood and 250–500 ml if the patient is in Trendelenburg position. Place the probe

Fig. 6.2 Proper probe position for the right upper quadrant (hepatorenal) view. Note the sonographer's grasp of the probe near the probe surface. This grip provides probe stabilization with the sonographer's hand in constant contact with the patient's body

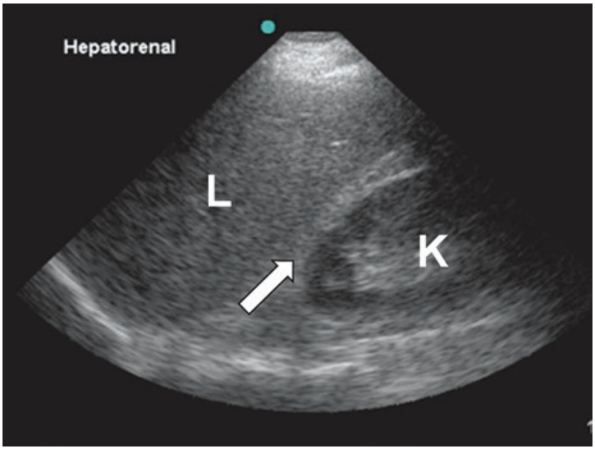

Fig. 6.3 Normal right upper quadrant (hepatorenal) view. Note the normal-appearing hyperechoic line (*arrow*) between the liver (*L*) and right kidney (*K*)

longitudinally (with the marker dot directed cephalad) near the midaxillary line between the 8th and 11th interspaces; this is the more typically used *intercostal* approach (Fig. 6.2). Slight counterclockwise rotation may aid in obtaining images between the ribs. A *subcostal* approach may also be used, but may require the patient to be cooperative and take deep breaths, which many cannot do. In either approach, angle, slide, or rock the probe until the right kidney is seen in a longitudinal axis (coronal plane), with the hyperechoic, hepatorenal, peritoneal reflection in between (Fig. 6.3 for normal RUQ view). The normal appearance (negative exam) should look like the kidney capsule is directly abutting the liver edge with nothing in-between. Intraperitoneal blood appears (acutely and classically) as an anechoic (black) stripe between the liver and kidney (Morison's pouch) and may have varying degrees of echogenicity based on degree of clot and fibrin stranding (Fig. 6.4). To assess for other bleeding sites, direct or slide the US probe cephalad

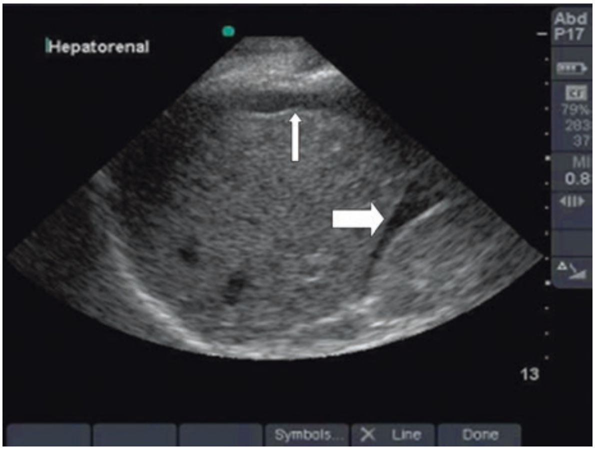

Fig. 6.4 Positive right upper quadrant scan, with *dark stripe* of blood in Morison's pouch (*large arrow*) and above liver in the right subphrenic space (*small arrow*)

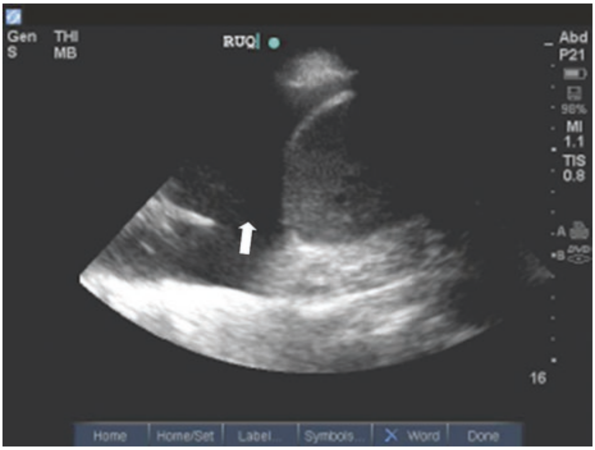

Fig. 6.5 Right-sided hemothorax, with hypoechoic collection of blood seen above the diaphragm (*arrow*)

and posterior, through and above the diaphragm, in a coronal plane. This allows you to assess for bleeding within the liver parenchyma and subdiaphragmatic space, as well as for hemothorax above the diaphragm. Blood or fluid in the thorax will have a V-shaped appearance, while subdiaphragmatic blood will be crescent shaped (Fig. 6.5). Studies have shown that US is more sensitive at detecting small amounts of fluid in the hemithorax than supine CXR. Remember on both the RUQ and LUQ views that identifying blood in the chest requires dynamic imaging to identify the location and movement of the diaphragm during normal respirations.

LUQ (Perisplenic or Splenorenal) View

This view is obtained with an intercostal approach. When placing the probe, start "more posterior and more superior" in comparison to the RUQ view. Reach over the patient, and place your right knuckles on the gurney near the left posterior

Fig. 6.6 Proper probe position for the left upper quadrant (splenorenal) view. Note the sonographer's hand placement with knuckles on the gurney, more posterior and superior than the RUQ probe placement

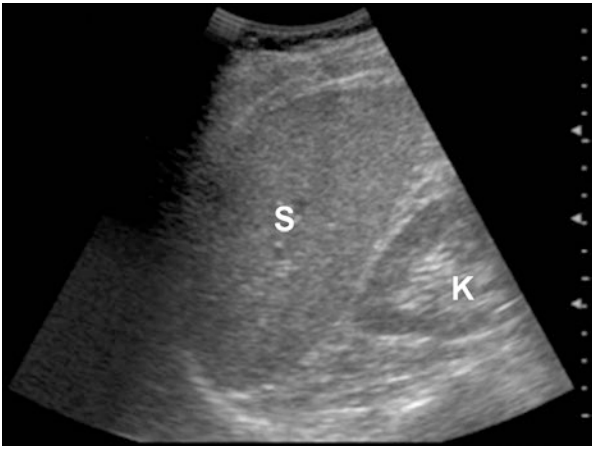

Fig. 6.7 Normal left upper quadrant (splenorenal) view showing the spleen (*S*) and the left kidney (*K*). Note the curvilinear, *hyperechoic line* (diaphragm) above the spleen

axillary line at the 9–10th interspace with the marker dot pointed cephalad to view the splenorenal junction (Fig. 6.6 for proper probe position and Fig. 6.7 for normal LUQ view). Slight clockwise rotation may aid in obtaining images between ribs. Sweep the probe anterior and posterior, as well as cephalad and caudal, to look for bleeding from a splenic injury. Similar to the RUQ view, you will look for any blood (black stripe) building up between the kidney and spleen. But you are not done there. Remember that on this side blood most often collects in the subphrenic space, so it is vital to also look above the spleen (Fig. 6.8). In doing so, we can see hypoechoic/anechoic fluid both below the diaphragm (hemoperitoneum) and above it (hemothorax) all in one view. While not the primary purpose of the EFAST, splenic parenchymal injury can also often be visualized as you perform this view.

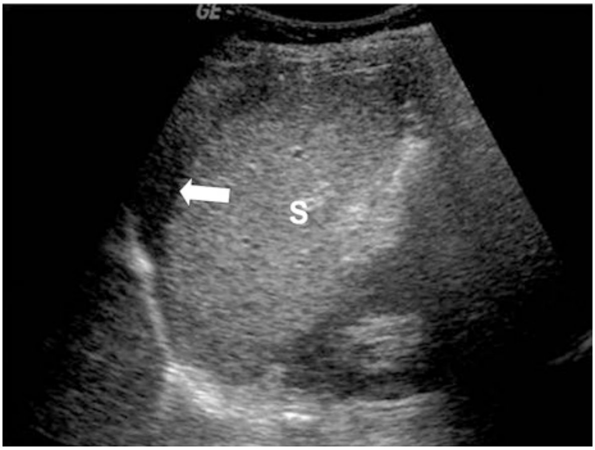

Fig. 6.8 Positive left upper quadrant scan, with *dark stripe* of subdiaphragmatic blood (*arrow*) seen above the spleen (S). Note the crescent shape of blood, as compared to hemothorax, which has a sharper or "v" shape

Fig. 6.9 Proper probe position for the transverse pelvic view. Note the sonographer's hand placement with caudal angulation of the probe to visualize the bladder

Pelvic View

In most patients, this is the most sensitive view for detecting intra-abdominal bleeding; as little as 100–200 ml of blood is detectable for a positive scan. Since a full bladder helps image quality, try to perform the EFAST before Foley catheter placement. If a Foley catheter has already been placed, infuse 200 ml of fluid into the bladder and clamp the catheter. Place the probe just above the symphysis pubis in the midline and angle the probe caudally to look into the pelvis (Fig. 6.9). Obtain both *longitudinal* (probe indicator pointed cephalad) and *transverse* (probe tip to the patient's right) views (see Fig. 6.10 for normal view). In females, free fluid is seen just posterior to the uterus if there is a small amount, but may surround the uterus if there are large volumes. In males, free fluid is seen behind or above the bladder (Fig. 6.11). A common false positive comes from overreading the seminal vesicles in males, which lie between the bladder and the prostate; notice their appearance and location as you practice on normal patients.

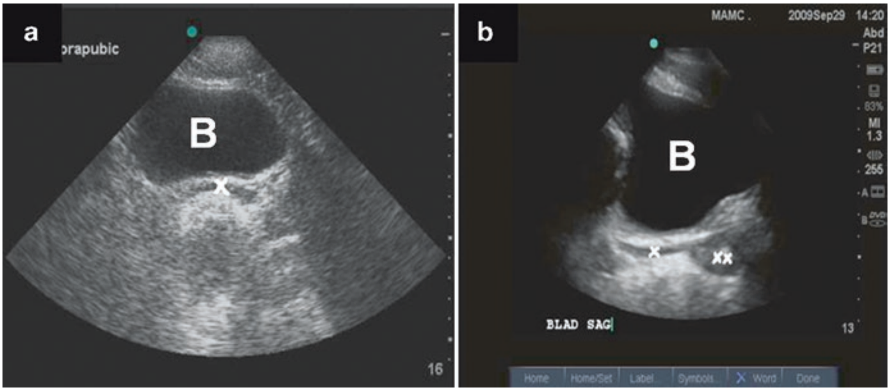

Fig. 6.10 Normal transverse (**a**) and longitudinal (**b**) pelvic views in a male patient (*B* bladder, *x* seminal vesicles, *xx* prostate gland)

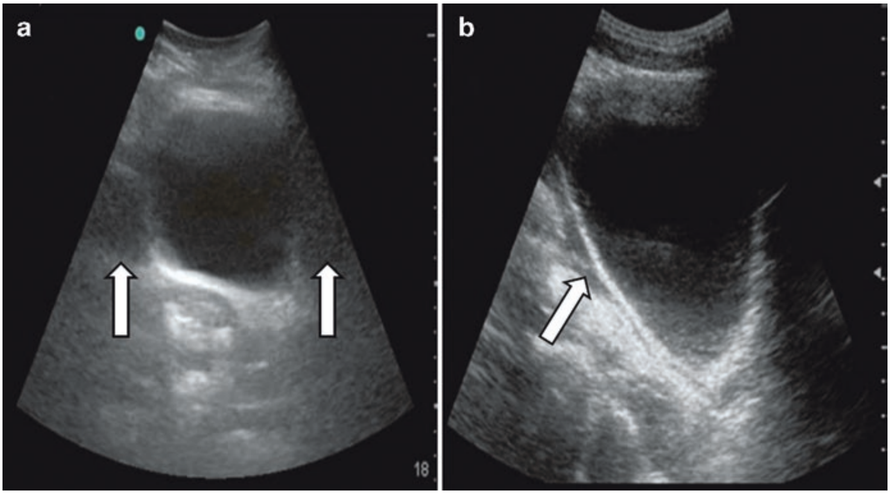

Fig. 6.11 Positive transverse (**a**) and longitudinal (**b**) pelvic views. Hypoechoic blood is seen on either side of the larger, anechoic (*black*) urine-filled bladder in (**a**) (*arrows*). In (**b**), the *dark stripe* of blood outside the bladder (*arrow*) tracks along the intestines and the posterior bladder wall, unlike the rounded edges of urine contained within the hyperechoic bladder walls

Pericardial View

In patients with penetrating trauma who are in extremis, you should do this view first, since hemopericardium would prompt you to perform emergent pericardiocentesis, thoracotomy, or sternotomy. The pericardium can be viewed using either the *subcostal* or *transthoracic* views. If the patient can tolerate it, the subcostal view is performed by placing the probe in the subxiphoid space with the beam directed at the left shoulder and the probe indicator toward the patient's right shoulder (Fig. 6.12).

Fig. 6.12 Proper probe position for the subcostal pericardial view. Note the sonographer's overhand grip of the probe. This overhand grip allows the US beam to be directed at a shallower angle to better visualize the heart. If an underhand grip is used, the bulk of the hand may not allow the proper angle to appropriately visualize the heart

For morbidly obese patients or those with significant abdominal pain or upper abdominal injury, try the transthoracic view. The parasternal long-axis view of the heart is usually performed with a phased-array probe obtained by placing the probe at the left fourth to fifth intercostal space just left of the sternum (Fig. 6.13 for the proper probe position and Fig. 6.14 for a normal parasternal long-axis view). Point the transducer indicator to the patient's right shoulder (10:00 position), and manipulate it until all four chambers of the heart are seen. Pericardial blood shows up as a black stripe between the myocardium and the hyperechoic pericardium (Fig. 6.15). Pericardial fat can show up as a dark stripe anterior to the right ventricle, but doesn't surround the entire heart. Slow and fine hand movements can greatly improve your image, or move to a different interspace if you cannot obtain a good ultrasound window at that position.

Pneumothorax Scan

US, in experienced hands, is about twice as sensitive as supine CXR in evaluating for pneumothorax in the trauma patient. Basically, you are looking for the normal pleural interface (parietal and visceral pleura) sliding across each other. This pleural line is just deep to the rib shadows and is seen as a white or hyperechoic line (Fig. 6.16). When air is present between this interface, as in a pneumothorax, the

Fig. 6.13 Proper probe position for the parasternal long-axis pericardial view. Note the sonographer's use of a phased-array probe to better see between ribs, and the hand stabilization against the chest wall

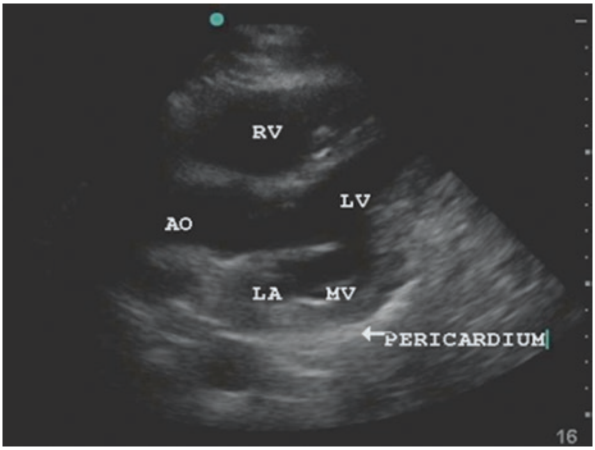

Fig. 6.14 Normal parasternal long axis view of the heart. *RV* right ventricle, *AO* aorta, *LV* left ventricle, *LA* left atrium, *MV* mitral valve

normal "lung sliding" is absent. This sliding can be evaluated using color power Doppler (CPD) or M-mode; however, neither is necessary if you can see normal sliding. Another normal finding is "comet tail" *artifacts*, which are white projections that are caused when US waves hit the normal pleural interface. These "rays" project down to the lower edge of the screen and are not seen if air is present. CPD,

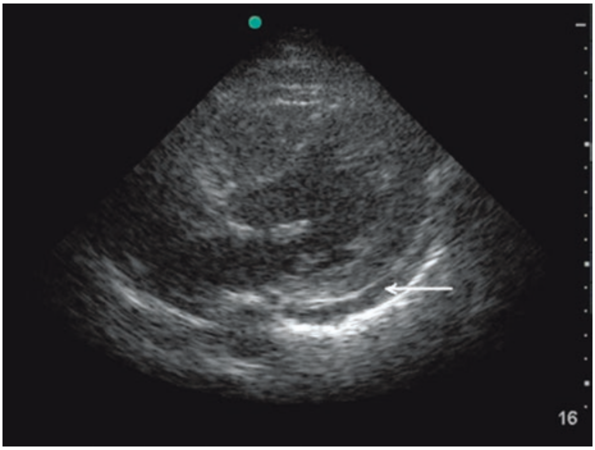

Fig. 6.15 Parasternal long-axis view of the heart with *dark stripe* of pericardial effusion (*arrow*)

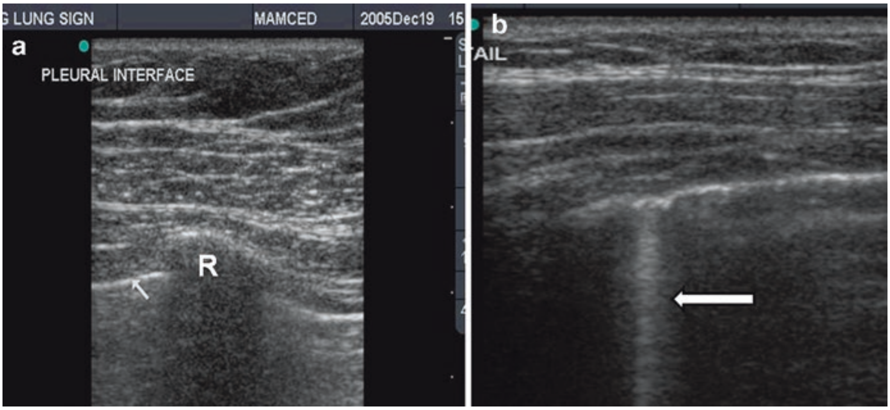

Fig. 6.16 Ultrasound evaluation for pneumothorax performed on anterior chest wall in midclavicular line. (**a**) The hyperechoic pleural line (*arrow*) is identified on the deep surface of the rib (*R*) which demonstrates posterior shadowing. Visible sliding pleural motion on real-time exam of this area rules out a pneumothorax. (**b**) Another finding of a negative examination is a comet-tail artifact (*arrow*)

M-mode, and comet tails all require motionless patients and therefore are of marginal utility in the austere environment (e.g., in a Humvee, FLA, Blackhawk, or if the patient can't hold still). The higher-frequency (5–10 MHz), linear transducers show shallow anatomy best and conform nicely to the chest in most patients and should be used to evaluate for pneumothorax. In the supine patient, air should collect anteriorly, so place the probe at the midclavicular space, identify the ribs first as landmarks for appropriate depth, then identify the pleural line just deep to the ribs, and look for normal lung sliding (Fig. 6.17). Repeat this two to three times in different anterior, sagittal planes for each hemithorax, sliding caudal over the anterior chest to the costal margins for each scanning plane. Pause between each interspace

Fig. 6.17 Proper probe position for the pneumothorax scan. Note the sonographer's use of a high-frequency linear probe, initially positioned at the highest point of the anterior chest

to confirm sliding, then as soon as you see normal sliding, move on. This should normally take less than a minute per hemithorax as long as you are sure there is normal sliding. For patients with hemodynamic instability or high suspicion of pneumothorax (penetrating shrapnel wounds, crepitus, etc.), place a tube thoracostomy if no sliding is seen. Occasionally, patients may arrive at your treatment facility with needle thoracostomies placed in the field. US demonstrating normal underlyinglung sliding indicates no pneumothorax and may obviate the need for immediate (or any following CT confirmation) tube thoracostomies. False-positive findings may be seen with (1) main-stem bronchus intubations (no sliding on opposite, normal lung), (2) patients with previous underlying lung disease with adhered pleura/scarring (usually older, civilian casualties), and (3) normal lack of sliding near the pericardial-pleural interface on the left.

Making Clinical Decisions with EFAST Findings

In combat, US findings are acted upon primarily based on the type of injury, clinical stability, and operating environment available. Patients with hemodynamic instability and clear indications for surgery should be taken emergently to the OR without significant delay for imaging. In penetrating injury, perform an EFAST when immediate surgery isn't clearly indicated, especially if multiple penetrating wounds are present, or when high velocity GSWs or other projectiles may have traversed multiple body cavities. In these patients, US may help to prioritize surgical interventions such as pericardiotomy, thoracotomy, laparotomy, or sternotomy. In patients going for emergent/urgent laparotomy, US can quickly rule out pericardial blood or pneumo-/hemothorax en route to or in the OR. EFAST findings can prioritize patients for evacuation and in mass casualty settings as well. In stable patients with blunt trauma, CT (if available) is a reasonable next choice when an EFAST shows intraperitoneal blood, and nonoperative management is being

Fig. 6.18 Proper probe position for the inferior vena cava scan

considered. CT should always be performed for an equivocal/indeterminate EFAST exam (if available) as long as the patient is stable. If CT is not available, then close observation with serial exams or a diagnostic peritoneal lavage (DPL) can be performed. In the unstable patient with an equivocal or indeterminate EFAST exam, you can quickly rule out abdominal hemorrhage as the source by performing a diagnostic peritoneal aspirate (DPA). Using either a standard DPL catheter or simply a syringe with an 18-gauge needle, aspirate as you penetrate the peritoneum (pelvis and/or paracolic gutters) with the needle. Any return of gross blood is positive and should prompt a laparotomy. See Chap. 5 for more on operative decision making, but try to do a quick EFAST if time allows in even the most critical patients since you can quickly get a lot of useful information that may guide the sequencing of initial surgical resuscitation.

Other Useful Applications

Evaluation of Hemodynamic Status/Central Venous Pressure (CVP) Measurement

US has additional utility in evaluating the patient in undifferentiated shock, looking for evidence of cardiac contusion/infarction, hypovolemic shock, pulmonary embolus, and cardiac tamponade. While specific echocardiography findings are outside the scope of this chapter, these are skills that can easily be picked up with some "off-the-cuff" training by the intensivists, cardiologists, emergency physicians, and trauma-trained surgeons with whom you may deploy. To estimate the CVP in any of these scenarios utilizing US, place the low-frequency probe in the sagittal plane (probe held longitudinally, marker cephalad) in the subxiphoid region to see the right atrial-vena caval junction (Fig. 6.18 for proper probe position and Fig. 6.19 for a normal IVC view). The IVC immediately adjacent to the right atrium (RA)

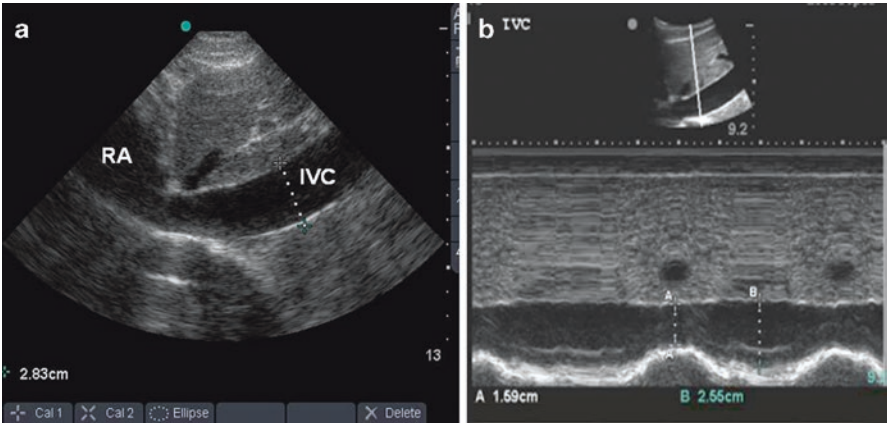

Fig. 6.19 Ultrasound evaluation of the inferior vena cava for volume assessment. (**a**) The inferior vena cava (*IVC*) is demonstrated as it enters the right atrium (*RA*) in longitudinal section, and the measurement of 2.8 cm suggests adequate intravascular volume. (**b**) M-mode evaluation of the vena cava is used to compare the diameter at inspiration (A) to that at expiration (B). Note that this vessel shows less than 50% collapse, again indicating adequate intravascular volume status

responds directly to the pressure of the right atrium and is a rough estimate of RA pressure. CVP *estimate* may be made based on the IVC size (normally 1.5–2.5 cm diameter) and response to inspiration in the following manner:

1. Total or significant IVC collapse at inspiration → Low RA pressure, patient needs volume resuscitation and/or hemorrhage control.
2. Normal sized IVC and moderate collapse (less than 50%) → Normal RA pressure.
3. Large-sized IVC and little or no IVC collapse → High RA pressure volume overload, cardiac tamponade, heart failure.

IVC estimation can be a helpful adjunct, but it should not be used as a sole-deciding factor early in the resuscitation. Make initial management decisions based on the patient's hemodynamic stability, history, and clinical evaluation of injuries. IVC estimation may certainly be useful later in the postoperative phase, as when receiving patients from an FST/FRST after damage control resuscitation or other "used" trauma. This is a very subjective measurement that also requires you to see many normal studies to recognize abnormals.

Triage

Mass casualty scenarios are always a possibility on today's battlefield. Most commonly, "mini-mass-casualty" scenarios are encountered when explosive devices injure several or more patients that you are called to assess. US can be an invaluable tool in gaining a lot of useful information in a short amount of time. If the surgeons and emergency physicians are busy leading the resuscitations, other trained team members can serve in this role. Radiologists, OB-GYN doctors, nurses, and even combat medics can be trained to perform EFAST when your trauma team and usual sonographers are tied up.

Procedural

Central venous catheter placement under US guidance is becoming the standard because data suggest there are fewer complications than when placing them using traditional landmark-based methods. If time allows in the stable patient, this is a great time to refine this skill as well. Other common procedures such as thoracentesis, paracentesis, percutaneous abscess drainage, and pericardiocentesis are greatly enhanced by the addition of ultrasound guidance. The principles of needle guidance are the same in these procedures as in central venous catheter placement, and developing this skill can pay major dividends.

Foreign Body/Soft Tissue/Musculoskeletal Applications

US can be very useful in identifying soft tissue foreign bodies, differentiating cellulitis from abscess, and evaluating other soft tissue injuries and infections. With practice, you can assess for long-bone fractures and dislocations without plain x-rays in even the most austere settings.

Other

While outside the scope of this chapter, other relatively easy scans that may be performed in the austere setting include gallbladder (stone/infection), hydronephrosis from kidney stone, AAA, and pregnancy scanning for confirming an intrauterine pregnancy (effectively ruling out an ectopic pregnancy except in a rare heterotopic pregnancy). Many other applications, such as retinal detachment or ocular foreign bodies, compression studies of the lower extremity venous system for DVT, and testicular ultrasound are easily performed with the basic US system that most units deploy with.

Advances and Future Applications

Recent innovations in miniaturization are leading to ever smaller and more portable US devices and transducers. With this portability come opportunities to expand US applications far forward, to the team or platoon level on the battlefield. Improvements in battery technology and life span will also extend the useful operational time frames of these devices. US use in ever more austere environments will assist in far-forward emergency care and triage.

With the expansion of US usage, training down to the medic level will be necessary. Many hospital-based nurses and medics are already currently utilizing (and are quite adept with) US to assist with peripheral venous access in emergency rooms and inpatient wards. Training programs in the special operations community are teaching specialized US applications to 18Ds that will continue to push the limits of US use as devices become lighter and more portable.

Advances in secure communication and data transmission are also making real-time telesonography possible. With this capability, images obtained in the field may be transmitted and interpreted by awaiting trauma teams, thereby speeding treatment and disposition. These innovations will only improve with time.

Final Thoughts

In conclusion, the utility and applications of ultrasound technology in combat trauma have been solidly established and continue to rapidly expand. The flexibility, portability, and ease of use of modern ultrasound platforms make this an ideal imaging modality which is becoming a standard adjunct to the physical examination. Advances in technology, communications, and training will greatly enhance the availability and incorporation of US in the prehospital setting, potentially altering the course of initial emergency management. Your investment of time in developing a solid foundation of ultrasound skills will pay great dividends in any forward-deployed or disaster scenario you may face.

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