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Bedside echocardiography in chest trauma

Diku P. Mandavia, MD, FACEP, FRCPC[a,b,*],
Anthony Joseph, MD, FACEM[c,d]

[a] *Los Angeles County–USC Medical Center, Room 1011, GH 1200 North State Street, Los Angeles, CA 90033, USA*
[b] *Keck School of Medicine, University of Southern California, Los Angeles, CA, USA*
[c] *Department of Emergency Medicine, Royal North Shore Hospital, St. Leonards, Australia 2065 Australia*
[d] *Department of Medicine, University of Sydney, Sydney, Australia*

Bedside ultrasonography has been used in emergency medicine for more than 15 years [1–3]. Emergency physicians successfully have integrated ultrasound (US) as the primary imaging modality for a number of emergent disorders. Of the well-established indications for bedside US, it is clear that the trauma patient benefits significantly from the use of this technique [4–10]. Trauma patients often arrive in the middle of the night when radiology backup is at a minimum, yet these patients often require the most extensive imaging evaluation of any emergency patient. This dichotomous relationship has required that trauma clinicians be experts in imaging injured patients, which includes bedside US techniques.

Many life-threatening disorders can be encountered in patients with chest trauma and, therefore, a rapid and thorough evaluation is compulsory. Chest radiography is essential and can detect many injuries including hemothorax, pneumothorax, diaphragmatic rupture, and rib fractures. Other specific findings can lead the clinician to suspect other disorders such as traumatic aortic injury (TAI). Helical CT has demonstrated excellent sensitivity and specificity in diagnosing this entity [11,12] and other serious chest injuries. Despite these advancements, however, some injuries can remain undetected. In particular, patients with penetrating chest injuries may harbor serious cardiac injury and a pericardial effusion that may be clinically difficult to determine. Beck's triad is unreliable, and previous work has shown that chest radiography and electrocardiography are not helpful in the diagnosis of

* Corresponding author.
E-mail address: mandavia@usc.edu (D.P. Mandavia).

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a pericardial effusion and acute tamponade [13,14]. In this scenario, bedside echocardiography can provide immediate, accurate information regarding the pericardium and the need for immediate surgery. It also can improve patient outcome. Plummer et al [15] demonstrated that early detection of a pericardial effusion by echocardiography improves outcome in patients with penetrating chest trauma. He conducted a 10-year retrospective review of penetrating cardiac injury and compared patients who received an emergency echocardiogram with those who did not. In this study, the echocardiography group had a shorter time to diagnosis (15.5 versus 42.4 minutes) and a better overall survival rate (100% versus 57.1%).

In the past, bedside echocardiography has been performed solely by cardiologists and cardiac sonographers. Because a formal echocardiography service often is not provided 24 hours per day at most hospitals, state-of-the-art trauma care has required that trauma clinicians play an increasing role in performing this technique [16]. Over the last decade, it has become increasingly apparent that trauma clinicians can be trained in this technique in a focused fashion that is beneficial to patients. The main objective of a focused echocardiogram is the primary finding of a pericardial effusion, and clinicians can be trained effectively in this modality after a relatively short period of time [17]. In a prospective study of 515 emergency patients, Mandavia et al [18] showed that emergency physicians reliably could examine the pericardium for a pericardial effusion with an accuracy of 97.5%. In this study, a combination of approaches including the parasternal long axis, subcostal four-chamber view, and the apical four-chamber view were used to detect 103 pericardial effusions. The Focused Assessment with Sonography for Trauma (FAST) examination includes the subcostal four-chamber view of the heart as part of the standard protocol and has been validated extensively [19,20]. Recognizing this trend and the evolving standard in trauma care, the Committee on Trauma of the American College of Surgeons revised their Advanced Trauma Life Support course to integrate rapid US assessment [21]. They recommend bedside US in the diagnosis of pericardial effusions when equipment and trained personnel are available. Course participants currently are taught the basics of the FAST examination, although formal hands-on US training has not yet been integrated.

Penetrating cardiac injury

Penetrating cardiac injuries are among the most lethal of all injuries and can present with complete hemodynamic stability, cardiovascular collapse with shock, or frank cardiac arrest. This extreme variation in presentation and propensity for sudden deterioration requires that a thorough evaluation be performed to rule out this injury [22]. Lacerations to the heart from small stab wounds to the chest tend to seal by clot and adjacent fat, causing

a natural predisposition to cardiac tamponade. In contrast, gunshot wounds to the heart cause extensive myocardial trauma and leave large rents in the pericardium where continued hemorrhage into a hemithorax often occurs [23]. Beck's triad often is referenced in the clinical diagnosis of acute cardiac tamponade but, clinically, it may be found in only 10% of cases [24]. Distended neck veins are difficult to evaluate due to cervical collars or may not be present because of concomitant hemorrhagic shock. Hypotension is not specific and may be caused by acute blood loss, tension pneumothorax, or spinal cord injury. Finally, muffled heart sounds are not reliably auscultated during a busy trauma resuscitation and also may be heard in patients with hemothorax or pneumothorax. Chest radiography adds little in the diagnosis of acute cardiac injury. Chronic medical effusions cause a slow distension of the pericardial sac and an enlargement of the cardiac silhouette, but this finding often is not seen in acute distension as it is in trauma. Intrapericardial air is diagnostic of pericardial violation but rarely is seen on plain radiography. Electrocardiography often does not show any reliable diagnostic findings in patients with pericardial effusions. Diagnostic pericardiocentesis often can lead to false-negative results because of the propensity of blood to clot within the pericardium and, thus, also cannot be relied on to exclude an effusion [24].

Acute cardiac tamponade in trauma occurs due to the fibrous anatomy of the pericardium that makes the pericardium inelastic and noncompliant compared with other body tissues. Sudden blood loss makes the right ventricle smaller, more compliant, and more susceptible to acute collapse. Simultaneously, blood accumulation in the constrictive pericardium causes an acute rise in intrapericardial pressure, subjecting the heart to right ventricular collapse and subsequent acute tamponade physiology. With small cardiac wounds, a slow rate of hemorrhage is much better tolerated, and acute tamponade may be delayed [22]. Small penetrating cardiac wounds may have a relatively slow rate of hemorrhage that can delay the appearance of acute cardiac tamponade. Acute tamponade is thought to be protective initially and then deleterious subsequently in penetrating heart injury. The initial tamponade effect helps limit the degree of exsanguination into the hemithorax, but this is a delicate balance because enlarging amounts of pericardial blood lead to a life-threatening rise in intrapericardial pressure. After the intrapericardial pressure exceeds the right ventricular diastolic pressure, acute tamponade ensues and rapidly leads to death unless the pericardium is decompressed [22].

In penetrating heart injury, early detection of acute cardiac tamponade, therefore, is imperative. Before the widespread implementation of echocardiography, subxiphoid pericardial window (SPW) was the initial method of evaluation in penetrating chest injury with wounds in proximity to the heart. SPW remains the "gold standard" for diagnosing heart injury but is an invasive procedure and requires general anesthesia. At most US trauma

centers, SPW currently is used when echocardiography is equivocal or in unstable, penetrating thoracoabdominal trauma patients who require emergent transfer to the operating room [22,25].

Bedside echocardiography allows a rapid and noninvasive method of examining the heart, pericardium, and pleural spaces and can be performed in the resuscitation suite after the primary survey has been completed. A number of studies have evaluated US in the setting of penetrating chest trauma. Freshman et al [26] conducted a study of 36 patients with penetrating precordial trauma. They detected four pericardial effusions using echocardiography and concluded that echocardiography was more efficient than ICU observation in making the diagnosis and less invasive than SPW or thoracotomy. Aaland et al [27] evaluated bedside echocardiography in 53 patients with penetrating chest injury and concluded that echocardiography was a sensitive method of evaluating these patients. Jimenez et al [28] conducted a prospective trial that compared SPW with echocardiography and likewise concluded that echocardiography could eliminate SPW in many patients. In both of these studies, echocardiograms were performed by cardiology fellows.

Nagy et al [29] evaluated echocardiography performed by trauma surgeons for detecting occult penetrating heart injury in 121 clinically stable patients. Using their selective pericardial window protocol (SPW performed after a positive echocardiogram), all significant cardiac injuries were identified and successfully repaired. Meyer et al [30] prospectively evaluated 105 hemodynamically stable patients with penetrating chest injury for occult heart injury. In this study, all patients underwent SPW and bedside echocardiography performed by surgeons. Echocardiography missed four significant injuries in patients with hemothorax but had a 100% sensitivity and a 91% specificity in patients without hemothorax. The investigators concluded that echocardiography was an acceptable diagnostic option in patients without hemothorax.

Rozycki et al [31] conducted a study of 247 penetrating truncal injury patients in whom there was no immediate need for operative intervention. There were 236 true negative patients and 10 true positive patients. Echocardiography had a sensitivity and a specificity of 100%, with a mean evaluation time of less than 1 minute. Mean time from US to operation was 12.1 minutes and all patients survived. The investigators concluded that surgeon-performed US was both rapid and accurate in the diagnosis of hemopericardium. Rozycki et al [32] also completed a prospective multicenter trial of US in patients with possible penetrating heart injury. In this large study, four centers recruited 261 patients with penetrating truncal wounds. Bedside echocardiography was performed by surgeons, cardiologists, or cardiac sonographers and had a sensitivity of 100% and an accuracy of 97.3%. Mean time from US to operation was 12.1 minutes. The investigators concluded that US should be the initial modality for the evaluation of patients with penetrating precordial wounds.

Technical considerations

The techniques of the FAST examination and transthoracic echocardiography are covered extensively elsewhere in this issue. In the emergency-department assessment of the patient with chest trauma, the primary focus is the evaluation of the pericardium and the detection of a pericardial effusion. It is important to understand that hemopericardium may not be completely anechoic as seen in most medical effusions. The presence of clot within the pericardium will cause the effusion to have internal echoes and a more hypoechoic appearance (Figs. 1–3) [33]. Echocardiography also can be used to perform a US-guided pericardiocentesis in a safe and expeditious manner [34,35]. Echocardiographic findings of acute tamponade, such as diastolic collapse of the right ventricle, will precede clinically apparent cardiovascular collapse and may be detected by bedside US. The finding of an empty pericardium may represent a large pericardial tear that prevents the accumulation of a pericardial effusion. In these cases, hemorrhage occurs into the hemithorax, and thus, a normal pericardial examination in the setting of a hemothorax should be interpreted with caution [30]. Similarly, an initial small pericardial hemorrhage may drain into the chest cavity after insertion of an intercostal catheter and result in an initially normal pericardial US examination.

The subcostal four-chamber view is a more commonly taught view in trauma, but the parasternal long-axis transthoracic approach offers some significant advantages [36]. The parasternal long-axis view is a direct, clear approach through the precordium, with the heart examined through its long axis [37]. The pericardium is dependent on this view, allowing easier

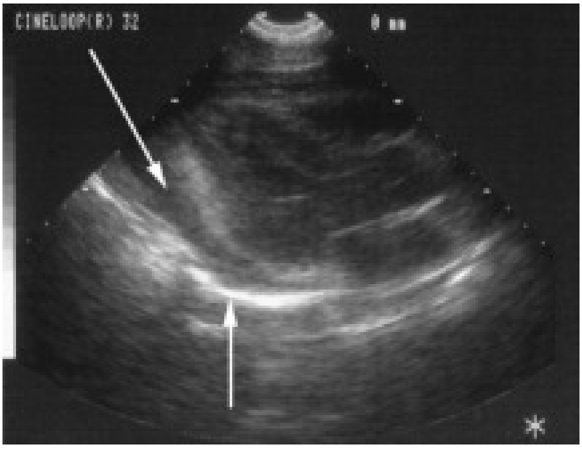

Fig. 1. Parasternal long-axis view of a pericardial effusion from a stab wound to the heart. Upper arrow points to hypoechoic effusion and lower arrow points to the hyperechoic posterior pericardium.

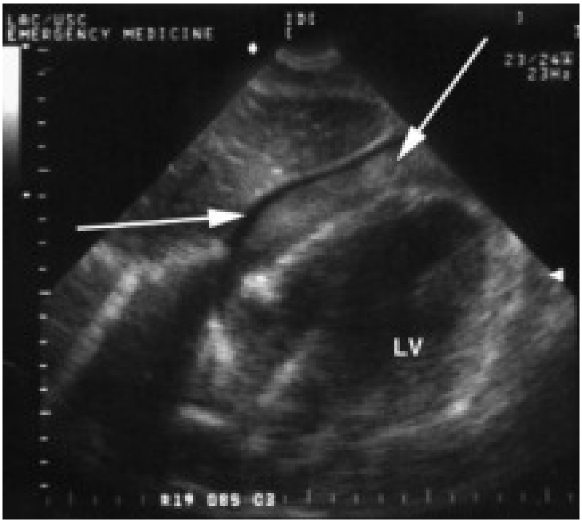

Fig. 2. Subcostal four-chamber view of hemopericardium with clotted blood. Right arrow points to the clotted blood seen as a circumferential hypoechoic area surrounding the heart. Left arrow points to a rim of anechoic and nonclotted blood. LV, left ventricle.

detection of small effusions. In this plane, the posterior pericardium and the descending aorta are recognized easily, allowing a differentiation between pericardial and pleural fluid [38]. On the parasternal long-axis view, the pericardial reflection will be noted to be anterior to the descending aorta,

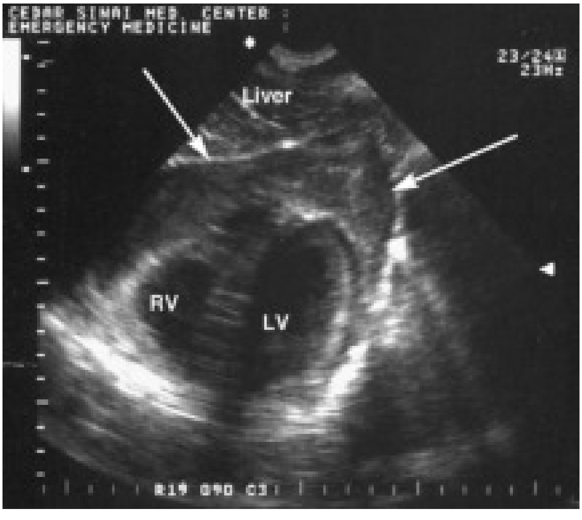

Fig. 3. Subcostal four-chamber plane of a stab wound to the heart with acute hemopericardium. Note the clotted hypoechoic appearance of blood within the pericardium (*both arrows*). LV, left ventricle; RV, right ventricle.

whereas the pleural reflection will be posterior to the aorta (Fig. 4). The parasternal view can be especially important given that many patients may have pericardial and pleural fluid collections. The subcostal approach also requires a cooperative patient because significant transducer pressure may be required in the subxiphoid area. Obese patients, who often have a small subxiphoid space, also pose a significant limitation to the subcostal approach. Given these considerations, the authors believe the parasternal long-axis approach to be a superior view, although knowledge of both techniques is optimal for an unselected trauma population.

Blunt cardiac injury

Myocardial rupture

Blunt cardiac rupture rarely is seen in the emergency department because most of these injuries are rapidly fatal, with death ensuing at the scene [39]. Increasing sophistication of emergency medical systems and rapid transport of patients to hospitals has allowed a small number of these patients to arrive at the hospital alive. High-speed motor vehicle crashes, pedestrian accidents, or a fall from a height account for most of these injuries, and serious coexistent trauma is common in these cases [40]. The ability of a patient to survive such a lethal injury partially depends on the integrity of the pericardium [23]. Most survivors of blunt myocardial rupture have had rapid exsanguination prevented by an intact pericardium. These unstable patients may survive for variable periods with hemopericardium and cardiac tamponade.

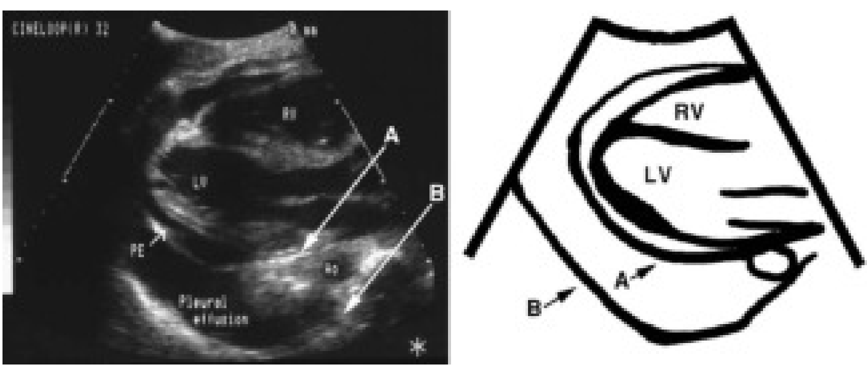

Fig. 4. Parasternal long-axis view of a pleuropericardial effusion. Fluid is noted within the pericardium (*small arrow* and PE), and the descending aorta (Ao) and pleural fluid is noted below this. Arrow A points to the more anterior reflection of the pericardium adjacent to the descending aorta. Arrow B points to the posterior reflection of the pleura adjacent to the descending aorta. LV, left ventricle; PE, pericardial effusion; RV, right ventricle.

Shock unresponsive to fluid and blood administration, massive hemothorax, elevated central venous pressure, and cyanosis of the head, neck, arms, and upper chest in the setting of acute chest trauma should prompt a search for myocardial rupture [41]. Bruit de moulin is a precordial murmur that sounds like a splashing mill wheel and also may be present [25]. Chest radiography usually will not help make the diagnosis but may detect other coexistent trauma. Electrocardiography may show a bundle branch block, axis deviation, or nonspecific findings.

Echocardiography can be invaluable in making the diagnosis, as illustrated by published cases [42–47]. Because of the infrequent nature of this injury, no large prospective trial has examined echocardiography specifically in the setting of myocardial rupture. Patients with an intact pericardium may show evidence of hemopericardium on a limited echocardiographic examination, whereas formal echocardiography may reveal further findings, including wall motion and valvular abnormalities.

Myocardial contusion

There is uncertainty as to the clinical significance of a myocardial contusion. The diagnosis is based on the microscopic finding of intramural hematoma in the absence of damage to the other structures such as valves, papillary muscles, coronary vessels, and pericardium [48]. Establishing the diagnosis likewise has been problematic, with the only true ‘‘gold standard’’ being direct visualization at thoracotomy or examination at autopsy. Furthermore, significant adverse cardiac events are rare in young patients, and a growing consensus of trauma experts favors the elimination of this diagnostic entity [49].

Echocardiographic findings in patients with myocardial contusion include small pericardial effusions, wall motion abnormalities (especially of the anterior wall of the right ventricle), wall thickness changes, and ventricular dilatation. The role of formal echocardiography performed by cardiologists has been evaluated as a screening test in patients with blunt chest injury. Karalis et al [50] prospectively examined the utility of echocardiography in 105 blunt chest trauma patients and concluded that only patients with acute complications benefit from echocardiography. Nagy et al [51] prospectively evaluated 315 patients with severe blunt chest trauma and completed extensive testing including electrocardiography, CPK-MB enzymes, and echocardiography. Overall, 22 patients were diagnosed with blunt cardiac injury, which was defined as evolving ST changes on electrocradiogram, dysrhythmias, elevated CPK-MB index, or hemodynamic instability. The investigators concluded that patients with blunt chest trauma who have a normal electrocradiogram, are hemodynamically stable, and have no dysrhythmias require no further testing. They also concluded that echocardiography is not useful as a screening investigation. Lindstaedt et al [52] performed a prospective study of 118 blunt

trauma patients. Their criteria for the diagnosis of myocardial contusion included echocardiographic evidence of akinetic wall motion or regional wall motion abnormality plus CK-MB enzyme elevation or electrocradiogram abnormality. They found no complications in 14 of 118 patients in whom they made the diagnosis, except for one case of left ventricular thrombus in the group followed for over 12 months. The investigators concluded that routine cardiac workup is not indicated and investigations should be limited to patients with complications. From the available literature, therefore, it appears that echocardiography (transthoracic or transesophageal) should be limited to patients with complications such as electrocradiogram changes, cardiac enzyme abnormalities, dysrhythmias, or hemodynamic instability. Unless the patient is unstable, echocardiography does not need to be performed in the ED. In addition, the use of bedside US by emergency physicians for detecting myocardial contusion has not been studied and currently is not recommended.

Valvular injury

Injury to cardiac valves after blunt or penetrating trauma is rare and usually coexists with other clinically significant cardiac injuries [53]. Autopsy findings have shown the aortic valve to be more frequently involved, followed by the mitral and tricuspid valves. Transthoracic and transesophageal echocardiography (TEE) are useful and able to detect right and left ventricular hypokinesis and acute aortic, mitral, and tricuspid incompetence. Invariably, these patients may have other thoracic injuries including pneumothoraces, which may limit the acoustic windows available for transthoracic echocardiography. The appropriate timing of surgical repair is difficult in these patients with multiple injuries, so TEE has been recommended as the investigation of choice because it allows accurate definition of the nature of the valve lesion and the underlying cardiac function [54].

Traumatic hemothorax

Early diagnosis of massive hemothorax (more than 1500 mL of blood in the thoracic cavity) is important to ensure prompt and appropriate resuscitation by placement of a chest tube and restoration of blood volume. The thoracic cavity is a common source of bleeding, although only 5% to 15% of these injuries require urgent surgery. Clinical signs may be difficult to elicit in the resuscitation room and a chest radiograph usually involves some delay. The FAST examination incorporates views of both lung bases and will confirm a clinical suspicion of hemothorax, allowing early intervention before radiographic identification.

The FAST examination includes views of the right and left upper quadrants. The right upper quadrant, when viewed from the eleventh rib

interspace in the midaxillary line, will include the liver parenchyma, the right diaphragm, and the pleural space superior to this. Any pleural effusion will be visible above the diaphragm as an anechoic space, and this may be the first clue to a traumatic hemothorax (Figs. 5 and 6). A closer examination of the pleural space may be made at higher interspaces to confirm the superior extension of the pleural fluid. During the examination of the left upper quadrant, by placing the probe longitudinally in the posterior axillary line in the tenth interspace, the left pleural space also may be inspected and will reveal an effusion or hemothorax if present.

There is some evidence that experienced sonographers are able to diagnose accurately traumatic hemothoraces. Sisley et al [55] found that surgeon-sonographers could accurately detect traumatic effusions in blunt and penetrating trauma patients compared with chest radiography. In a study of 360 patients with 40 effusions, focused thoracic US detected 39 effusions, whereas chest radiography detected 37, with a slightly higher sensitivity for US (97.5%) compared with chest radiography (92.5%) and a comparable specificity (99.7% for each). More important, the investigators also noted that the time to perform the US was faster compared with the time to obtain a chest radiography (1.3 versus 14.2 minutes). US also was able to detect even small hemothoraces because the fluid detected ranged from 60 mL to 1100 mL. Ma and Mateer [56] compared US to chest radiography in a study of 240 trauma patients. In their study, US had a sensitivity of 96.2% and a specificity of 100%. Rozycki et al [57] also conducted a study of 47 patients and 140 thoracic US examinations in critical care patients. They demonstrated a sensitivity of 83.6%, a specificity of 100%, and an accuracy of 94% in detecting pleural fluid and concluded

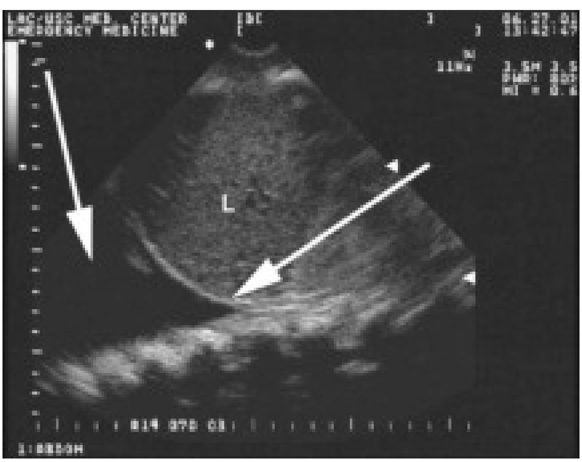

Fig. 5. Hemothorax seen above the right diaphragm as an anechoic area (*left arrow*). The diaphragm is recognized as a hyperechoic line just superior to the liver (*right arrow*). L, liver.

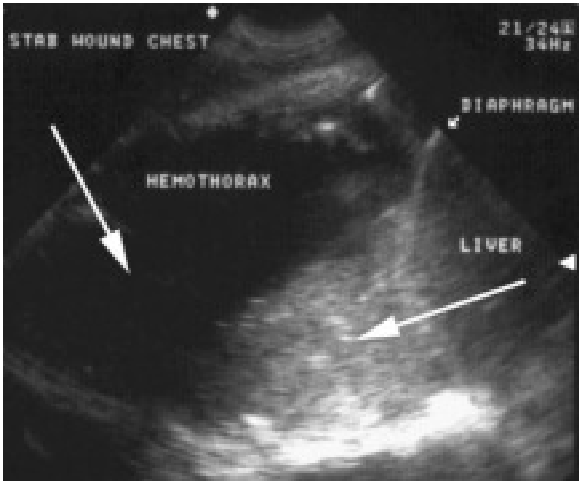

Fig. 6. Hemothorax seen above the right diaphragm secondary to a stab wound. Left arrow points to anechoic nonclotted blood; right arrow points to echoic clotted blood.

that US can reliably detect pulmonary effusions in critically ill patients. Abboud and Kendall [58] recently published a prospective study of 155 patients using CT as the comparative standard. In their study, US had a low sensitivity of 12.5% and a specificity of 98.4%. Their interpretation of these contrasting results was that CT detects very small pulmonary effusions, many of which may not be clinically significant in the acute resuscitation, and they concluded that further work is needed to clarify the size of hemothoraces detected by US.

Traumatic aortic injury

The aorta is the most frequently injured of the major intrathoracic vessels in blunt and penetrating trauma. Penetrating trauma usually causes a full-thickness injury that is rapidly fatal, whereas a blunt mechanism such as sudden deceleration may result in partial or complete tears. The most common site for TAI after blunt trauma is the descending aorta just proximal to the ligamentum arteriosum, followed by the ascending aorta or arch (Fig. 7). Most patients who arrive in the ED have partial-thickness injuries in which the intima and media are torn but the adventitia remains intact. Of these patients, 50% will rupture in the first 24 hours and 80% in the first week if the diagnosis is not made [48]. Chest radiography may show a widened mediastinum and other specific findings or it may be normal. Conventional angiography has been the "gold standard" investigation for diagnosis of this condition but has been challenged seriously by helical CT and TEE.

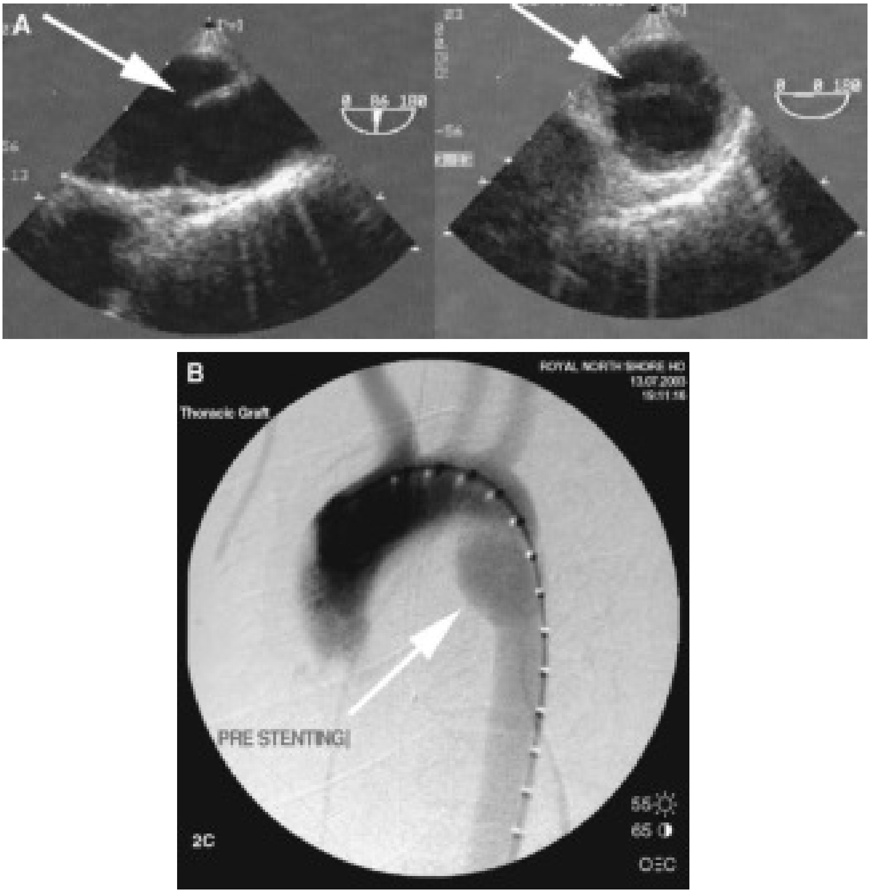

Fig. 7. (*A*) Long and short axis of descending aorta seen on TEE in a young adult with blunt chest trauma. Arrows point to intimal injury of the aorta. (*B*) Aortography of previous case confirms traumatic injury of the aorta (*arrow*).

TEE has been used in the operating room since the 1980s, with the introduction of two-dimensional transducers. The 5.0- to 7.5-MHz probes allow higher resolution, and the close proximity to the aortic and cardiac structures results in higher-quality images with better spatial resolution [59]. Doppler helped with the investigation of blood flow and assessment of valvular function. The biplane TEE in the 1990s provided a longitudinal plane that allowed imaging of vertically aligned structures such as the superior vena cava, right ventricular outflow tract, and the ascending aorta. The multiplane transducer allowed even greater visualization of the cardiac structures. The advantages of TEE over aortography include the ability of TEE to be performed at the bedside with a short diagnostic time of 15 to 30

minutes and to be performed intraoperatively in patients undergoing lifesaving operations for other injuries.

The use of TEE requires special training and is operator dependent. It also is relatively contraindicated in patients with cervical injury and absolutely contraindicated in those with esophageal injuries. TEE provides limited views of injury in the proximal ascending aorta and main branches and may miss injuries such as a partial rupture of the subclavian artery.

TEE is ideal for use in the hemodynamically unstable patient who is unsuitable for transfer to the radiology suite for chest CT or arch angiography. Although it can be used at the bedside and in the potentially unstable patient, definitive airway management may be required before performing TEE. It is being increasingly used as the diagnostic test of choice for TAI in the unstable patient. It also can be used to diagnose other conditions such as acute valvular rupture and pericardial effusion or tamponade. The abnormalities found by TEE in confirmed cases of TAI are shown in Box 1 [60,61].

Smith et al [62] confirmed the accuracy of TEE in the diagnosis of TAI compared with surgery, aortography, and autopsy. In this study, cardiologists performed TEE successfully in 93 of 101 patients and detected TAI near the aortic isthmus in 11 of 93 patients. The findings were confirmed in 10 of the 11 patients by surgery, aortography, and autopsy, resulting in a sensitivity of 100% and a specificity of 98%. There was one false-positive examination. The investigators concluded that TEE was sensitive and specific for the detection of TAI and can be used safely and accurately in critically injured patients. The findings of this study were confirmed in a similar study by Vignon et al [63] in which TEE was performed on 31 consecutive trauma patients with a suspicion of TAI based on a major deceleration mechanism or chest radiography findings of a mediastinum >8 cm. The investigators found two subsets of injury. Ten patients had subadventitial injury and 2 had tears confined to the intima only. There were 18 patients with a normal aorta confirmed on aortography and

Box 1. Transesophageal echocardiography findings in traumatic aortic injury

Dilated aortic isthmus
Intimal flap with pseudoaneurysm
Medial flap
Intimal tear or mural thrombus
Intramural hematoma
Mediastinal hematoma (usually anteromedial)

1 patient with a false-negative study (a 2-mm medial tear found at autopsy). The patients with subadventitial tears were taken to the operating room and the patients with tears confined to the intima were treated conservatively. Smith et al [62] concluded that TEE should be the initial imaging modality for suspected TAI because of its portability, safety, accuracy, and beneficial impact on patient care.

Goarin et al [61] compared TEE with angiography and CT in a 9-year retrospective study. They evaluated 209 blunt trauma patients and demonstrated a 98% sensitivity and a 100% specificity of TEE for diagnosing TAI. They recognized that TEE also detects small injuries of unclear clinical significance but concluded that TEE is an accurate method for the diagnosis of aortic injury.

Buckmaster et al [64] conducted a prospective trial that compared TEE and aortography in 160 patients. TEE correctly identified all 14 injuries in this study with a 100% sensitivity. The investigators concluded that TEE is diagnostic and can obviate the need for aortography. They recommended aortography when TEE is equivocal, is contraindicated, is not tolerated, and when other vascular injuries that would be missed by TEE are suspected.

TEE may be more sensitive in diagnosing small aortic intimal injuries compared with aortography or CT scan of the chest. A small study by Kepros et al [65] suggested that intimal tears <2 cm completely resolved within a few days. The study supported the safety of nonoperative management, which included beta-blockers, follow-up TEE, and invasive monitoring. The clinical relevance of these small intimal tears requires further study.

There has been some uncertainty regarding the relative accuracy of helical CT and TEE in the detection of TAI. Vignon et al [60] prospectively compared the diagnostic accuracy of mutiplane TEE and helical CT in the detection of TAI and cardiac injury in patients who suffered major chest trauma. Both modalities were reliable for the detection of subadventitial tears to the aortic isthmus or the ascending aorta. Helical CT detected one laceration of the innominate artery not seen on TEE, whereas TEE was more sensitive in diagnosing superficial (intima and media injuries) aortic injuries and blunt cardiac trauma such as acute valvular incompetence. Hence, these investigators recommended restricting the use of angiography to those with contraindications to CT or TEE, inconclusive results from other investigations, and suspected aortic branch injury.

In summary, TEE should be used as a primary tool to diagnose TAI in patients who are too unstable for aortography or CT and who require emergent surgery for other life-threatening injuries. The main advantages are portability and rapidity; however, it appears to be user dependent like most other US applications. Presently, TEE is performed primarily by cardiologists and anesthesiologists and has not yet become part of the armamentarium of the emergency physician.

Traumatic pneumothorax

There has been much recent interest in the extension of the FAST examination to include the thorax to detect the presence of an anterior pneumothorax that may not be clinically or radiologically obvious. Although these pneumothoraces are not immediately life threatening, it is essential to make the diagnosis, especially if the patient requires intubation for any reason (eg, head injury or imminent surgery) because positive-pressure ventilation may transform a simple pneumothorax into a tension pneumothorax. As US technology has improved rapidly over the last decade and the machines have become more compact, there is increased interest in the ability to diagnose a potentially life- threatening pneumothorax in situations such as air flight or space flight where radiology equipment is not practical.

This technique was first described in a veterinary journal when it was used to diagnose and treat a pneumothorax in a horse [66]. Since that time, there has been increased interest in the medical literature regarding the application of this procedure in humans. The technique involves the use of a 7.5-MHz linear probe applied over the anterior chest wall usually in the third or fourth interspaces in the midlateral clavicular line or the anterior axillary line. Normal lung–to–chest wall interface allows the detection of the ''lung sliding'' sign (Fig. 8). Lung sliding is the to-and-fro movement with respiration that is seen as a hyperechoic line between the chest wall and the aerated lung and represents the visceral and parietal pleura [67].

A normal examination also may show comet-tail (short-range reverberation) artifacts, which are high-amplitude echoes tapering and reducing in brightness with depth [68]. These artifacts arise from the visceral pleura,

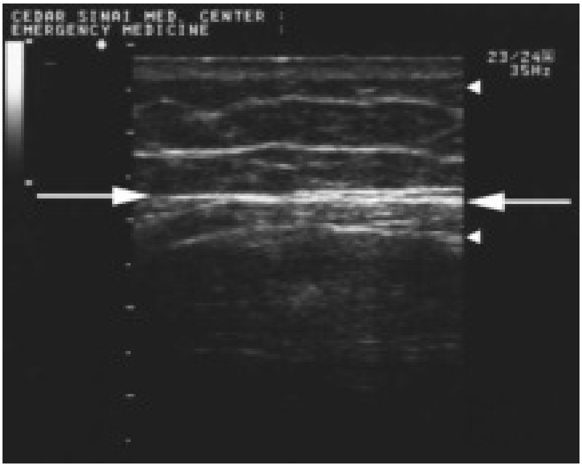

Fig. 8. Sonographic appearance of a normal lung using a linear array 7.5-Mhz probe. The hyperechoic line represents the pleura (*arrows*). Absence of the lung-sliding sign (seen in real time) indicates a pneumothorax.

which is a highly reflective surface. The presence of these artifacts indicates the absence of a pneumothorax. Conversely, when a pneumothorax is present, the air between the visceral and parietal pleura does not allow the sound waves to be transmitted to the visceral pleura and, therefore, comet tails are not produced and lung sliding does not occur. The apparently normal lung should be scanned first to demonstrate lung sliding and any comet tails. Lung sliding may be absent in patients with pleural scarring and difficult to see in the presence of subcutaneous emphysema.

Rowan et al [69] compared the accuracy of thoracic US with that of supine chest radiography in the detection of traumatic pneumothoraces, using chest CT as the reference standard. They prospectively studied 70 trauma victims who presented to the ED over an 8-month period. Patients in respiratory distress who required immediate tube thoracostomy were excluded. Twenty-seven patients underwent CT of the chest and 11 of them were found to have a pneumothorax. Thoracic US detected 11 of 11 pneumothoraces, whereas chest radiography detected only 4 of 11, yielding sensitivities of 100% and 36%, respectively. Thoracic US had one false positive study in a patient with substantial bullous emphysema on CT.

Another study of 382 patients (mostly trauma) compared chest radiography to thoracic US for the detection of pneumothorax and demonstrated sensitivities of 100% and 95.5%, respectively [70]. There were 39 pneumothoraces seen on chest radiography, but only 37 on US, with two false negative studies due to the presence of subcutaneous emphysema. It would appear from the available evidence that US can be used to detect occult pneumothorax and may be incorporated into the FAST examination.

Summary

Bedside US has an established role in the evaluation of chest trauma patients. Transthoracic echocardiography and TEE can be used to obtain critical information at the bedside for many emergent conditions, including the immediate detection of hemopericardium and acute aortic injury. More recent work has demonstrated that US also can be used to detect hemothoraces and pneumothoraces with accuracy. These diagnostic techniques can improve patient outcome and are within the scope of practice of emergency physicians and trauma surgeons. Physicians caring for trauma patients should be familiar with these techniques.

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