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Ultrasound in trauma

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Point-of-care ultrasound is well suited for use in the emergency setting for assessment of the trauma patient. Currently, portable ultrasound machines with high-resolution imaging capability allow trauma patients to be imaged in the pre-hospital setting, emergency departments and operating theatres. In major trauma, ultrasound is used to diagnose life-threatening conditions and to prioritise and guide appropriate interventions. Assessment of the basic haemodynamic state is a very important part of ultrasound use in trauma, but is discussed in more detail elsewhere. Focussed assessment with sonography for Trauma (FAST) rapidly assesses for haemoperitoneum and haemopericardium, and the Extended FAST examination (EFAST) explores for haemothorax, pneumothorax and intravascular filling status. In regional trauma, ultrasound can be used to detect fractures, many vascular injuries, musculoskeletal injuries, testicular injuries and can assess foetal viability in pregnant trauma patients. Ultrasound can also be used at the bedside to guide procedures in trauma, including nerve blocks and vascular access. Importantly, these examinations are being performed by the *treating physician* in *real time*, allowing for immediate changes to management of the patient. Controversy remains in determining the best training to ensure competence in this user-dependent imaging modality.

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Introduction

Over the last decade, there has been a remarkable increase in clinician-performed ultrasound in many specialties. Improvements in technology have led to improved image quality and smaller, simpler and more affordable machines. At the same time clinical research, improved education and increasing awareness of the many uses of ultrasound have enthused clinicians around the globe.

Ultrasound does not have to compete with or replace other imaging and assessment modalities, but it complements them. It has a unique role in assisting the clinician in the trauma setting. Ultrasound is portable, can be immediately accessed, does not have to interrupt resuscitation, is safe, repeatable and gives dynamic information that yields a diverse range of diagnostic information and can guide procedures.

In trauma, ultrasound is now frequently used in the pre-hospital setting, in disaster situations, during patient retrieval and in the hospital setting from the emergency department through to operating theatres, intensive care units and the wards. It is used by pre-hospital medical staff, emergency physicians, trauma surgeons, anaesthetists, radiologists and sonographers.

There are many diverse indications for the use of ultrasound in trauma (Table 1). In major trauma and the critically ill patient, ultrasound is used to assist in identifying immediate life threats, in directing and prioritising interventions and in guiding resuscitation. In regional trauma, ultrasound can give diagnostic information about a vast range of pathologies including individual organ, musculoskeletal, soft-tissue and vascular injuries. Finally, ultrasound can be used as a guide to interventional procedures, ranging from vascular access and nerve blocks to foreign-body removal.

The major limitation of ultrasound remains that it is operator dependent, with training and experience as well as simple inter-operator variability playing a role. Ultrasound is also patient dependent; some patients are more difficult to image; this is often due to obesity but other factors can also play a part.

Whilst new uses of ultrasound continue to be found and enthusiasts advance the boundaries of what can be done with ultrasound, the major challenge that faces us is how to ensure adequate training and competence in this relatively complex but extraordinarily useful imaging modality.

The aim of this article is to describe the various roles ultrasound has in the assessment and management of the major trauma patient.

Major trauma

The history of ultrasound in major trauma

In the early 1970s, several articles were published in the English literature describing the utility of ultrasound in defining solid-organ injury in trauma.[1,2] In the 1980s, in Germany, the use of ultrasound in trauma assessment was being used and studied[3–6]; however, these studies were largely ignored in the United States (US), Britain and Australia, perhaps because of language barriers and simple lack of recognition. In the early 1990s, a flurry of interest in trauma ultrasound resurfaced in the United States. A large amount of research and many publications recognising the role of ultrasound in assessing for haemoperitoneum in the undifferentiated trauma patient were completed. Concurrent advances in technology, commercial investment, publicity and marketing all led to the current proliferation of interest and investment in clinician-performed ultrasound and trauma ultrasound.

Current role for ultrasound use in major trauma

Current management of patients who have suffered potential major, multisystem trauma, either blunt or penetrating, is to use a team approach to rapidly identify and address immediate life threats using clinical and radiological means.

Table 1
Uses of ultrasound in trauma.

Major trauma
- Assessment of the Basic Haemodynamic State
  - Review response to haemodynamic interventions
- Focussed Assessment with Sonography for Trauma (FAST)
  - Haemoperitoneum
  - Haemopericardium
- Extended FAST (EFAST)
  - Pneumothorax
  - Haemothorax
- Intravascular filling status
  - Inferior vena cava size and respiratory variation

Regional trauma
- Cardiac and Thoracic aortic injury (trans-thoracic and trans-oesophageal echocardiography)
  - Blunt myocardial injury
  - Penetrating cardiac injury
  - Traumatic aortic injury
- Fractures
  - Sternal fractures
  - Rib fractures
  - Other fractures and dislocations
- Soft-tissue injury
  - Muscle and tendon injuries
- Ocular trauma
  - Intra-ocular foreign bodies
  - Posterior ocular assessment in the presence of hyphaema or major periorbital haematoma
- Testicular trauma
- Pregnancy viability assessment
- Foreign body detection
- Assessment for raised intracranial pressure
- Vascular injury
  - Pseudoaneurysm
  - Arteriovenous fistula
  - Perivascular haematoma
  - Thrombosis
  - Dissection

Procedural guidance
- Intubation confirmation and endotracheal tube placement
- Nerve blocks for analgesia
  - Intercostal/paravertebral blocks for rib fractures
  - Limbs blocks for limb trauma
- Guide for compartment pressure monitors
- Vascular access
  - Central and peripheral venous
  - Arterial
- Foreign body removal

Paracentesis/Intercostal drainage guidance

Advanced Trauma Life Support (ATLS) teaching describes the primary survey as the initial assessment period during which major life threats are identified and their management commenced. Using a team approach means the traditional steps of the primary survey can be carried out concurrently (see Table 2). Ultrasound assessment can be integrated into the primary survey where appropriate but should not interfere with nor delay other assessment and resuscitation. Ultrasound may assist with airway, breathing and circulation assessments, and even in assessing dysfunction of the central nervous system (CNS). At this stage, however, the widely accepted and commonly used roles for ultrasound in the primary survey are in assessing for blood in the peritoneum, pleural space and pericardium, as well as assessing for pneumothorax and guiding vascular access.

Table 2
Steps of the primary survey and potential roles of ultrasound.

Step in primary survey	Potential roles for ultrasound
A = Airway	Determine tracheal position
	Confirm ETT placement and position
B = Breathing	Assess for pneumothorax[a] and haemothorax[a]
C = Circulation	Assess for haemoperitoneum[a]
	Assess for haemopericardium[a]
	Assess for haemothorax[a]
	To guide peripheral or central venous access[a]
	Assess intravascular filling
D = Dysfunction (CNS)	Assess optic nerve sheath diameter as a reflection of intracranial pressure
E = Exposure	

[a] Indications widely accepted and in common use in trauma management.

Focussed assessment with sonography for trauma (FAST) is a rapid, four-view ultrasound examination carried out during the primary survey that assesses for haemoperitoneum and haemopericardium. Extended FAST (EFAST) adds assessment for haemothorax, pneumothorax and intravascular filling to the FAST examination.

Ultrasound has many further potential roles in assessing regional trauma as part of the secondary survey, but is beyond the scope of this article.

Focussed assessment with sonography for trauma (FAST)

The term focussed assessment with sonography for trauma (FAST) was coined by Rozycki et al.[7] in 1995. It describes a limited (four-view) ultrasound assessment of the abdomen looking for haemoperitoneum, and of the heart looking for haemopericardium. The aim is to identify life-threatening intra-abdominal bleeding or cardiac tamponade with a view to expediting definitive surgical management. It does not aim to exclude abdominal or thoracic injury.

- It helps to detect haemoperitoneum and haemopericardium.
- The primary benefit is to rapidly direct appropriate operative interventions in unstable patients.
- It is useful in both blunt and penetrating abdominal trauma.
- A high specificity means a positive FAST indicates an intra-abdominal injury.
- Moderate sensitivity means a negative FAST (apparent absence of free fluid) does not exclude significant injury.
- FAST alters the management of trauma patients[8–10], such that
  - there is more rapid disposition to the operating theatre,
  - it indicates a more rapid search for other causes of hypotension when negative,
  - it reduces the number of computed tomography (CT) scans and diagnostic peritoneal lavage examinations (DPLs) performed and
  - it is associated with shorter hospitalisations, less complications and lower charges.
- At this stage, however, there is little conclusive evidence that its use improves patient survival.[11]
- Extended FAST (EFAST) includes assessment of the thorax for haemothorax and pneumothorax.

The FAST examination was initially developed to assist in assessing the hypotensive, undifferentiated, blunt trauma patient; however, it also has a utility in penetrating trauma. A negative FAST should be interpreted with caution in both blunt and penetrating traumas as significant injury may not have associated free fluid, and free fluid may take time to develop. Rozycki et al.[12] found that 22% of abdominal injury in adults was not associated with free fluid. This rises to 37% in paediatric abdominal trauma.[13] Injuries frequently not associated with significant free fluid include injuries to bowel and mesentery, pancreas, liver and spleen contained by their capsules and retroperitoneal injuries including renal injuries.[14]

Beck-Razi et al. found that FAST enabled immediate triage of casualties to laparotomy, CT or clinical observation. They recommended that, because of its moderate sensitivity, a negative FAST result with strong clinical suspicion demands further evaluation.[15]

Indications and role of FAST in blunt trauma

An algorithm for the FAST scan is shown in Fig. 1. The indications for FAST are described below:

1. Unstable patients with potential thoraco-abdominal injury[16]
   - These patients are too unwell for transfer to CT.
   - Laparotomy is indicated if FAST is positive (i.e., free intra-abdominal fluid).
   - Immediate therapy directed towards haemothorax or pericardial effusion if either of these are detected.
   - Negative or equivocal FAST should prompt rapid search for other potential causes of hypotension, a repeat FAST and if uncertainty still remains a diagnostic peritoneal lavage (DPL).
2. Stable patients with high clinical suspicion of thoraco-abdominal injury
   - Highly significant mechanism, abdominal pain, abdominal wall bruising, macroscopic haematuria, unexplained transient hypotension, equivocal or unreliable physical examination (intoxication or distracting injury)
   - CT represents the diagnostic modality of choice. Contrast-enhanced comprehensive ultrasound may come to represent an alternative modality particularly in those in whom iodinated contrast (allergy) or radiation (pregnancy) makes CT a far less attractive option.
   - Positive FAST will prioritise and expedite other imaging, and if the patient deteriorates prior to CT, immediate directed intervention can be delivered.

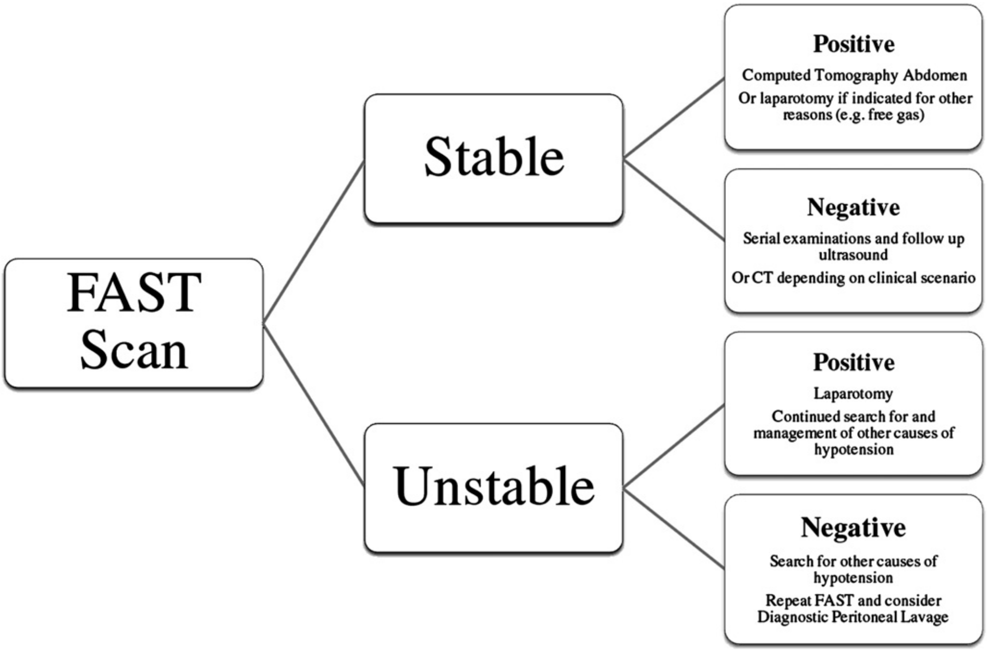

Fig. 1. FAST-oriented algorithm: all patients suffering blunt abdominal trauma have a FAST scan and further investigation and management then depends on their haemodynamic status and results of investigations.

3. Stable patients with low clinical suspicion of thoraco-abdominal injury
   - Admission with serial negative FAST examinations in conjunction with monitoring and normal serial clinical examinations for at least 8 h is advisable. At this point, if a patients remain well, has normal urinalysis and consistently normal haemoglobin levels, they may be safely discharged with advice to return if concerning symptoms develop.[11,17]

Indications and role of FAST in penetrating trauma

The aim of FAST in penetrating trauma is to determine whether one or more of the abdominal, pericardial or pleural cavities has blood in it. This indicates breach in the integrity of the cavity and potentially significant injury. Lack of free fluid in the abdomen does not exclude significant injury, as penetrating bowel injury is frequently not associated with free abdominal fluid.

1. Unstable patient with multiple wounds
   - It helps to locate and quantify bleeding and direct initial therapeutic measures.
2. Unstable patients with a single penetrating thoraco-abdominal wound of uncertain trajectory
   - To locate and quantify bleeding and direct initial therapeutic measures.
3. Stable patient with one or more penetrating wounds
   - When it is not certain whether immediate surgery is required
   - To locate and quantify bleeding and direct therapeutic measures.

Other imaging and/or surgical exploration is generally required to exclude significant injury.[18,19]

Practice points

Abdominal free fluid:
- Sensitivity 42–98% (most studies 64–98%); specificity 95–100%,
- Sensitivity improves with experience,
- Sensitivity is better for larger volumes of free fluid, and in hypotensive patients requiring laparotomy for intra-abdominal bleeding the volume of fluid is likely to be large
- Serial FAST examination may improve sensitivity as bleeding continues to create larger collections of free fluid.

Sensitivity and specificity for the FAST examination vary considerably in the literature. Sensitivity ranges from 42% to 98% and specificity from 95% to 100%. Several factors contribute to the large variation in sensitivity, and include inclusion criteria, equipment and techniques used, experience of the operators and reference standards.[20] One study showing sensitivity of only 42% excluded unstable patients, thereby excluding the very patients that FAST is most useful for, and in whom the fluid collections would be the largest and easiest to detect.[21] Another criticism of studies showing poor sensitivity is they include patients with trivial amounts of free fluid and no significant abdominal injury as false-negative FAST examinations. Whilst strictly correct, the clinical implication of a trace of free fluid in the face of no abdominal injury is negligible. The majority of studies show sensitivity ranges from 64% to 98%.[7,9,12,22–32]

The ability to detect free fluid is volume dependent especially for inexperienced operators.[14,33,34] Fortunately where hypotension is secondary to bleeding into the peritoneal space, a large volume of free abdominal fluid will be present. Once again this reinforces the fact that FAST is useful to exclude life-threatening abdominal bleeding in the undifferentiated hypotensive trauma patient, but does not exclude significant abdominal injury when it is not associated with peritoneal bleeding. Examples of positive FAST scans are shown in Figs. 2–4.

Practice tips: solid-organ injury

- 22% of adults with intra-abdominal injury have no free fluid.
- 37% of children with intra-abdominal injury have no free fluid. This means relying on the presence of free fluid as a marker of intra-abdominal injury will miss injuries.
- The ultrasound appearance of abdominal organ injury is highly variable and changes with time after the injury.
- Sensitivity of comprehensive ultrasound examination (not just a FAST scan) for individual solid-organ injury is moderate and specificity high.[20]
- The technical skill and knowledge needed to comprehensively assess the abdomen with ultrasound is far greater than for FAST.[14]
- Some studies suggest CT scan may be avoided in patients where there is a clinical suspicion of abdominal injury (particularly useful in pregnant women or children).[35,36]
  - When the patient is stable and does not require urgent surgical intervention.
  - Comprehensive abdominal ultrasound with good-quality images is attained.
  - Monitoring and serial examination/investigation are available (including cardiotocography (CTG) for women in the later stages of pregnancy).
- The use of contrast agents in ultrasound significantly improves detection of solid-organ injury and is an area still under investigation.[37–40]

Ultrasound to detect solid organ injury

Whilst FAST is not designed to detect organ injury directly, more comprehensive ultrasound can often detect organ injury. The appearance of organ injury is very variable. A hepatic laceration may appear hypoechoic, isoechoic, echogenic or have varied echotexture. With time, the appearance of an injury changes, often becoming hypoechoic and being more apparent; in the acute instance, however, injury is often difficult to detect as a clot has an echotexture similar to that of the liver. In addition to the varied appearance of the injury, the sonographer must be able to attain adequate views throughout the organ being examined. This is frequently difficult, particularly with the spleen, where the diaphragm, lung and gastric contents or bowel can make adequate windows difficult to attain.

As well as lacking sensitivity, comprehensive abdominal ultrasound is time consuming and requires a great deal more experience. It is inappropriate to spend time defining individual organ injury in the unstable patient or in the patient where CT scan can be arranged easily.

Several studies have suggested comprehensive ultrasound rather than just FAST examination in those patients in whom CT scan would ideally be avoided – particularly pregnant women and children. This route of management should always be undertaken with the knowledge that ultrasound will miss some injuries and other means need to be undertaken to ensure none of these are significant. Serial examination for bowel injury, CTG for placental abruption, urinalysis and serial blood tests for renal injury should be performed as clinically indicated.

In the last few years, contrast-enhanced ultrasound imaging has been widely investigated, particularly for evaluation of liver lesions. Ultrasound-specific contrast, which consists of microbubbles that resonate when interrogated by ultrasound, highlights the vascular and microvascular circulation. Ultrasound contrast agents now offer the possibility of accurately recognising or excluding abdominal solid-organ injuries and assessing their location and size. Traumatic solid-organ injuries such as lacerations or haematomas are generally characterised by lack of flow. The technique can also highlight active bleeding with contrast-medium extravasation. Complete ischaemia due to traumatic avulsion is readily recognised with complete absence of contrast media.[40]

Whilst contrast-enhanced ultrasound may evaluate solid-organ injuries, bowel and mesenteric injuries remain best assessed by CT scan.

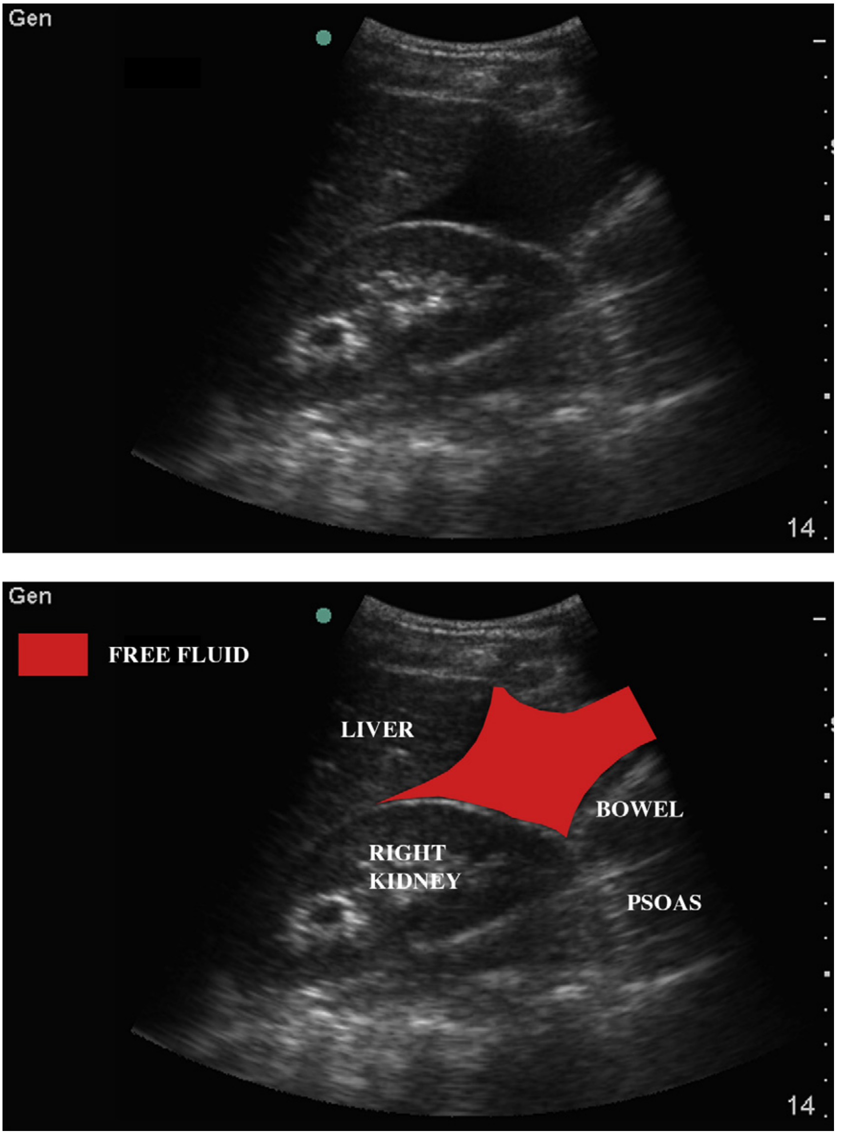

Fig. 2. Positive FAST scan showing blood anterior to the right kidney.

Haemopericardium

- Sensitivity is 100% for penetrating trauma.
- Specificity is 97% for penetrating trauma.

It is well known that physical examination is unreliable in determining the presence of pericardial effusion and even tamponade. Less than 40% of those with cardiac tamponade display Beck's triad of hypotension, raised jugular venous pressure and muffled heart sounds.[41,42] In the emergency department setting, where neck veins are obscured by collars and heart sounds muffled by

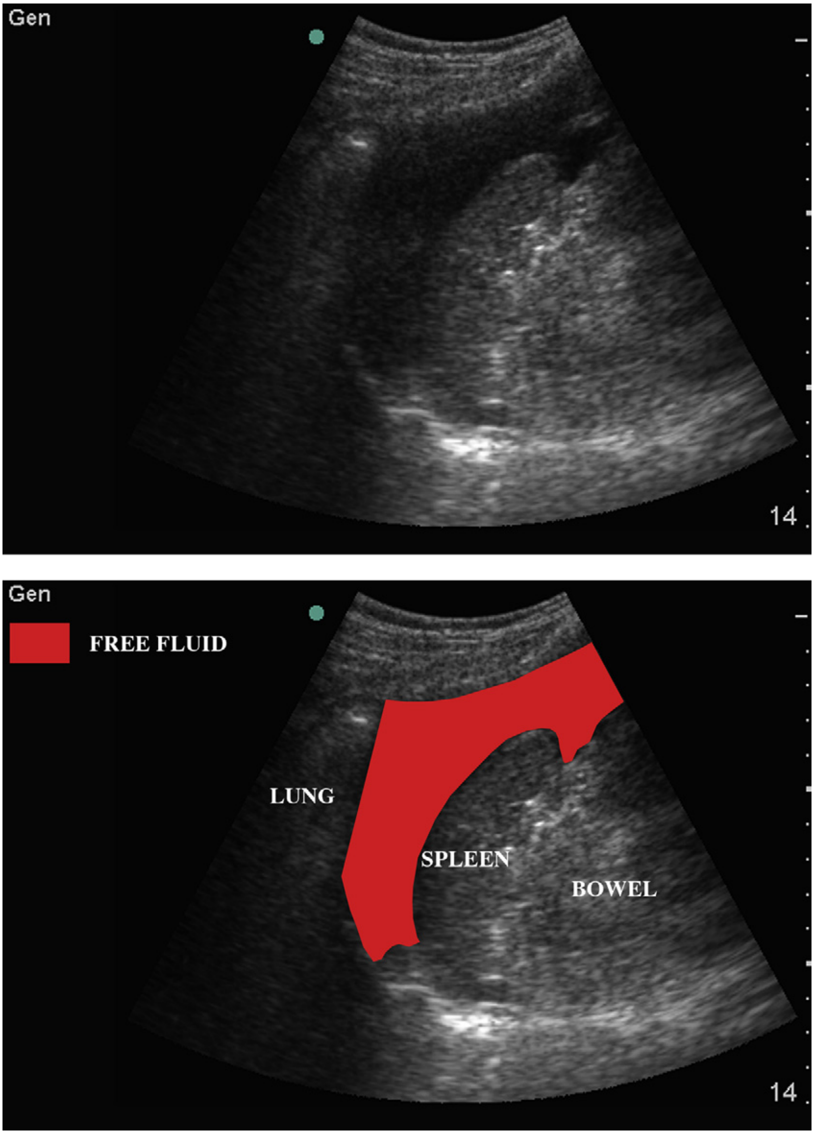

Fig. 3. Positive FAST scan showing blood around the spleen.

pneumothorax, haemothorax or the busy department itself, it is thought that detection of the classic triad would occur even less often.[43] It has been shown that bedside echocardiography is good for detecting cardiac tamponade in the setting of penetrating trauma. Plummer et al. showed that bedside echocardiography reduced time to diagnosis and disposition and improved survival.[44] In penetrating trauma, sensitivity of FAST for cardiac tamponade approaches 100%, with specificity around 97%.[31,45,46] An example is shown in Fig. 5.

The data are not so clear for blunt trauma and is limited essentially to case reports.[47] This is because blunt myocardial rupture and haemopericardium is rarely seen in a hospital as most of these injuries are rapidly fatal.[48,49] In patients with these severe injuries, there is often major co-existent

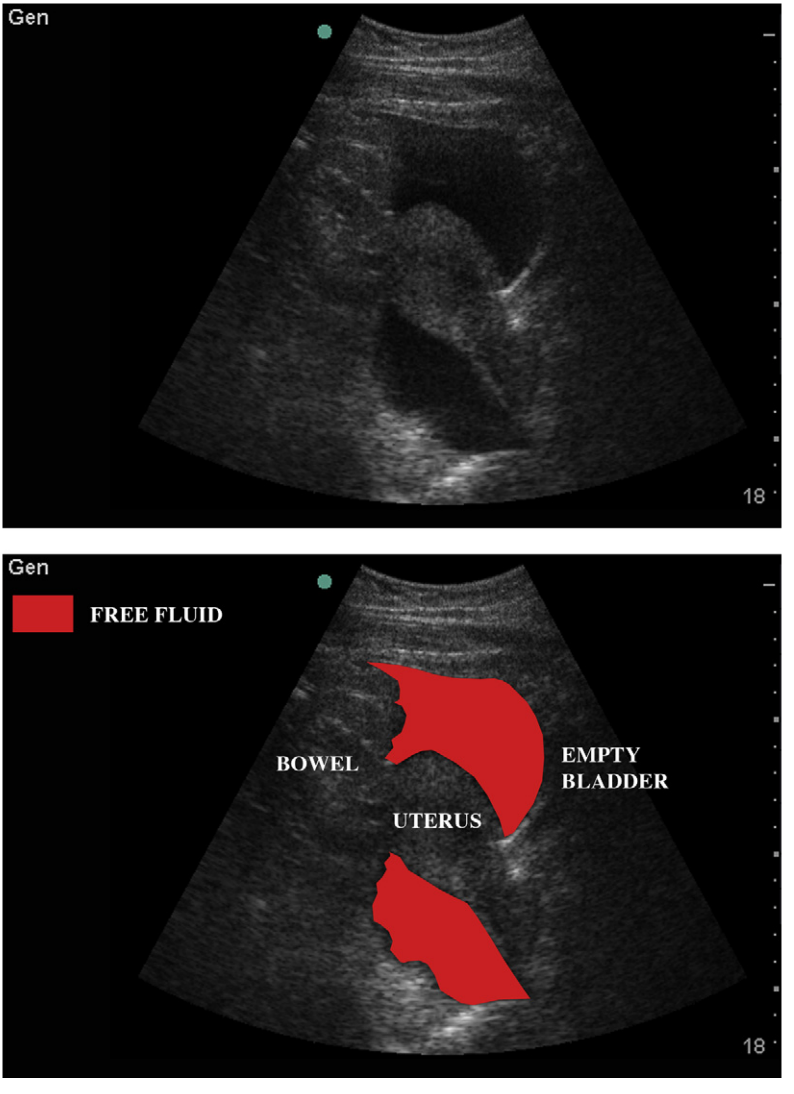

Fig. 4. Positive FST scan with blood anterior and posterior to the uterus. Note that the bladder is not seen because it is empty.

trauma, making trans-thoracic echocardiography more difficult.[49] Surgical emphysema, flail chest, pneumothorax and inability to position the patient ideally all make echocardiography more difficult. In patients in whom adequate views are attainable, however, it seems the pericardium can be assessed.

Haemothorax and Pneumothorax

As with free intra-abdominal blood, free fluid in the pleural space (e.g., haemothorax) gathers in the most dependent position. In the supine trauma patient, this is along the posterior thoracic wall (see Fig. 6). The upper quadrant views of the FAST scan can evaluate the lung bases for free fluid above the diaphragm. Haemothorax appears as an anechoic triangle filling the costophrenic angle;

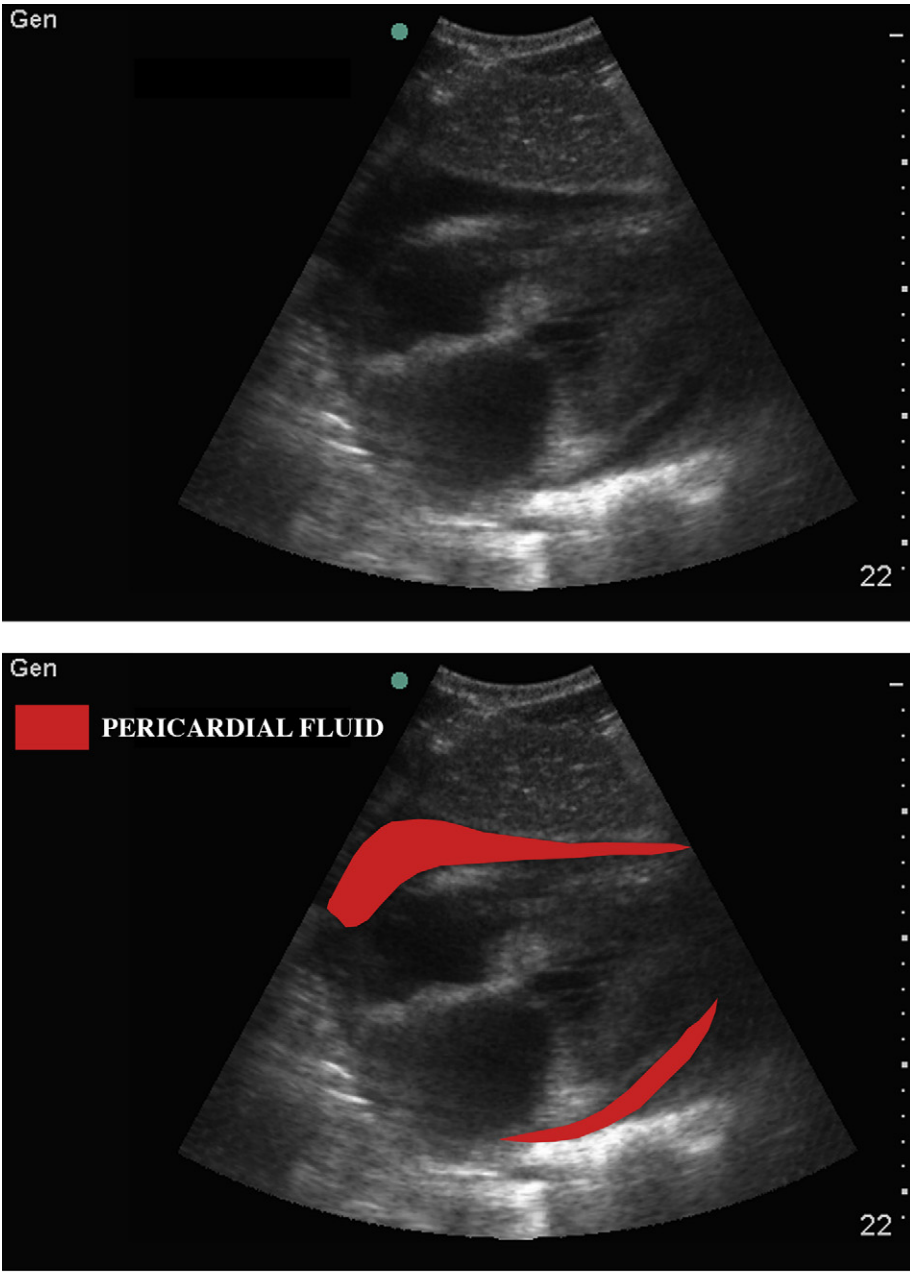

Fig. 5. Pericardial effusion is shown with blood seen adjacent to the right and left ventricles.

its size can be roughly estimated by examining higher interspaces to determine the extension of the fluid.[43]

Very small collections may not extend laterally enough to be detected. These are evident on CT scan, usually not on plain films, and their clinical significance is unlikely to be high.[53] Ultrasound can detect very small pleural collections if the patient is able to be moved and the most-dependent areas

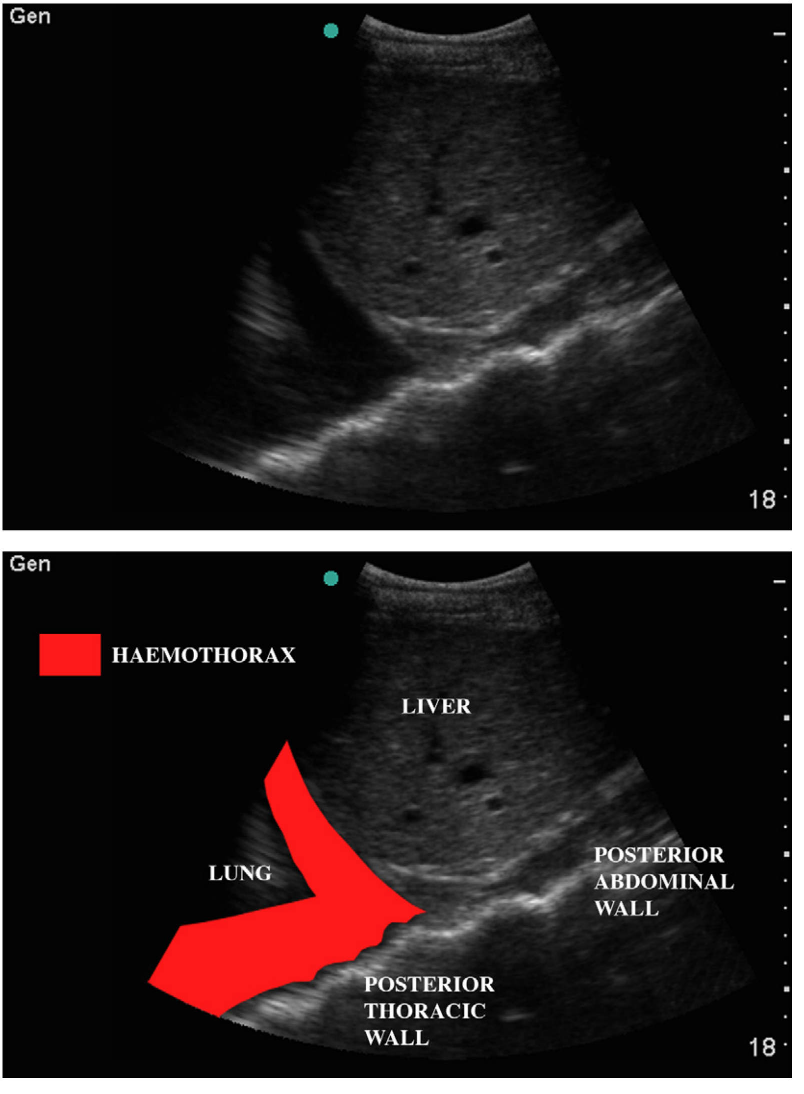

Fig. 6. Haemothorax is seen with blood in the costo-phrenic angle, appearing as black space between the liver and the posterior thoracic wall.

interrogated with ultrasound. Allowing the patient to sit on the edge of the bed and examining the costophrenic angle posteriorly and laterally will allow the detection of even very small fluid volumes.

In the supine patient, free intra-thoracic air collects at the highest intra-thoracic point, against the anterior chest wall. An anteroposterior chest film will often not show a small-to-moderate-sized pneumothorax that later becomes apparent either clinically or on CT scan. The normal appearance of the pleura is shown in Fig. 7. When there is no pneumothorax the two pleural layers can be seen to slide against each other during respiration (sliding sign). Comet tail artifacts are also event, being created by the presence of small amounts of interstitial fluid in the adjacent lung. When a pneumothorax lies between the pleural surfaces both the sliding sign and comet tail artifacts are lost. It is these relatively subtle findings that reveal the presence of a pneumothorax.

Practice tips: haemothorax

- Sensitivity is 83.6–97.5% in the supine patient and specificity 99.7–100%.[46,50–52]
- Ultrasound can be performed more rapidly than chest radiography.[46]

Practice tips: pneumothorax[54–56]

- In the supine trauma patient, pneumothorax can be occult (not readily visible) on plain chest radiography in 36–75% of cases.
- Sensitivity of ultrasound for pneumothorax is 92–100% and specificity 94–99%.
- The difference between small, medium and large pneumothoracies can be differentiated by ultrasound.
- Surgical emphysema can obscure the window; however, it is almost always associated with pneumothorax itself.
- False negatives are usually 'miniscule' pneumothoracies. False positives may occur with bullous emphysema and previous pleuradesis.

The paediatric population

- Many paediatric abdominal injuries do not have associated haemoperitoneum.
- Sensitivity of FAST for detecting haemoperitoneum is 80% and specificity 95%.
- Sensitivity of FAST at detecting any intra-abdominal injury is 66% (because many paediatric intra-abdominal injuries do not have free fluid).
- Sensitivity of comprehensive abdominal ultrasound at detecting haemoperitoneum and/or intra-abdominal injury is 82%.
- Ultrasound should not be used as the sole assessment tool of the abdomen in paediatric abdominal trauma, but is useful when used as part of a clinical assessment protocol.

Ultrasound is commonly used as a diagnostic modality in the paediatric population because it is non-invasive and avoids sedation and irradiation. In trauma, however, 31–37% of intra-abdominal injuries in children do not have associated haemoperitoneum.[13,57] Sensitivity of ultrasound in paediatric trauma has previously been reported in the ranges 33–93%.[58–60] A recent meta-analysis found the sensitivity of FAST for haemoperitoneum to be 80%[61], but when only studies with more rigorous methodology are included it fell to 60%. The sensitivity of FAST at detecting any intra-abdominal injury was only 66%.

Comprehensive abdominal ultrasound searching for free fluid as a marker of intra-abdominal injury and searching for individual organ injury with or without free fluid found the sensitivity of ultrasound at detecting any intra-abdominal injury to be 82%.[61]

The value of the FAST examination and comprehensive ultrasound in the paediatric population is more controversial than in the adult population as the number of missed injuries is likely to be higher. Luks et al. showed that although ultrasound alone was not always diagnostic, there were no false-positive or false-negative results when used in conjunction with a clinical protocol.[62]

Practice tips: a reasonable clinical protocol would be:

1. Laparotomy for unstable patients with haemoperitoneum, or those with clear evidence of hollow organ rupture.

2. CT for those where there is free fluid or evidence of organ injury on ultrasound or if there is high clinical suspicion of abdominal injury.
3. Comprehensive ultrasound and monitoring with serial clinical assessment in those with lower clinical suspicion.

Time to perform FAST

In experienced hands, a FAST scan can be completed very rapidly, usually in less than 3 min. Wherrett et al. showed that in the positive FAST, the time to result was 19 ± 5 s and in the negative 154 ± 13 s.[10]

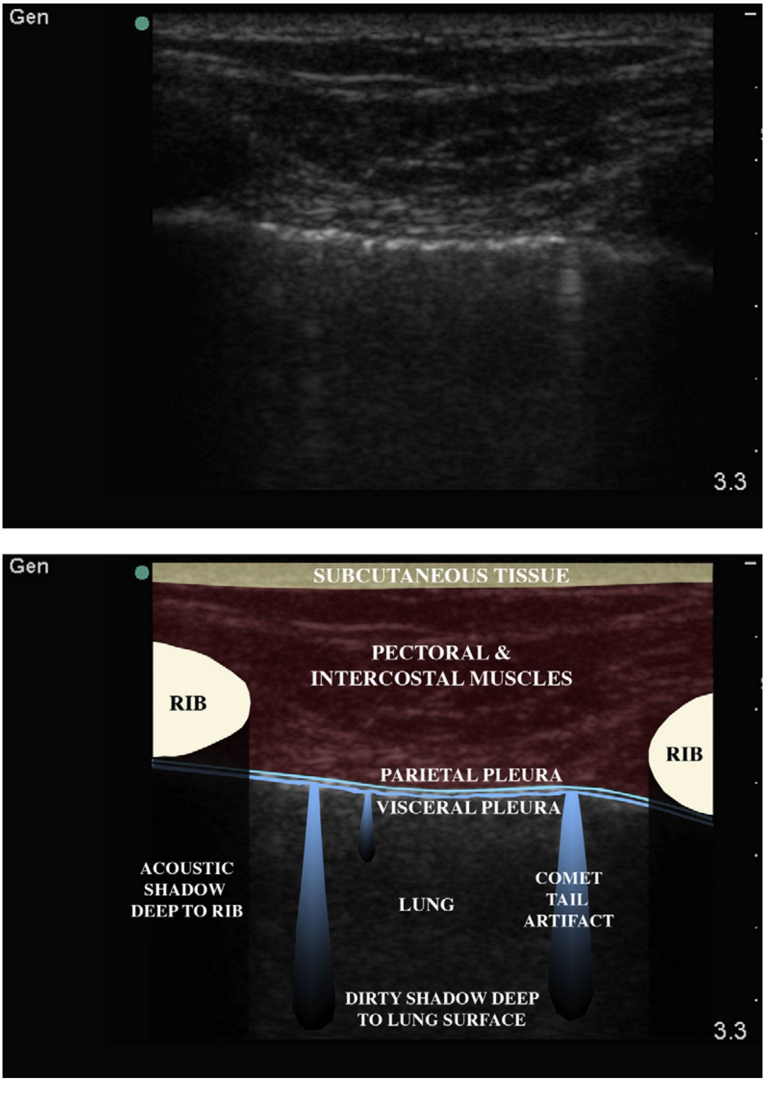

Fig. 7. Normal pleural ultrasound showing the pleura as bright plane with comet tail artefacts.

Amount of fluid required to be detected and quantification of the fluid

- Sensitivity to detecting fluid is volume dependent, especially for inexperienced operators.
- The volume required to be readily detected on a FAST scan is in the range of 200–620 ml.
- Several scoring systems exist to quantify fluid, but have not been extensively used or validated.

Several studies have explored the question of how much free fluid can be detected using ultrasound. It is clear that the greater the amount of free fluid the easier it is to detect.[33,34]

In the setting of the hypotensive trauma patient where the FAST is used as a screening test to determine whether there is enough bleeding into the abdomen to account for hypotension, the ability to detect small amounts of free fluid is not important – we are not excluding injury, just trying to work out if there is life-threatening haemorrhage.

The average volume of fluid detectable by the FAST scan ranges from 250 to 620 ml.[33,63] As examiners gain more experience, their sensitivity improves – Gracias et al. demonstrated that examiners who had performed over 100 examinations were significantly better at diagnosing smaller fluid volumes.[33]

The acoustic window created by the full bladder enhances detection of fluid in the pelvis, which is often the first place for fluid to collect.[64] Generally the FAST should be performed before the urinary catheter is inserted – and as part of the primary survey; however, some will have empty bladders at the time of presentation. Some centres fill the bladder with sterile fluid to assist in pelvic views. If the bladder is empty, views should be declared as inadequate to exclude the presence of pelvic free fluid.

It has been shown that placing the patient in the Trendelenburg position (5° head down) improves fluid detection in the upper abdomen, presumably by draining fluid from other locations, including the pelvis, to the upper quadrants. In a study by Abrams et al., the minimum volume required to detect free fluid fell from 668 to 443 ml when patients were placed in the Trendelenburg position.[65]

There are several scoring systems that have attempted to quantify the amount of free fluid in the abdomen objectively, because the use of terms such as a trace, small, moderate or large amounts are not thought to be clinically useful and show considerable inter-observer variability.[66]

Huang et al.[67] developed a system to quantify the amount of free fluid, with 1000 ml or more being the key volume they wished to be able to determine. Their system assigned 1 point to each anatomic site in which free fluid was detected (left upper quadrant (LUQ), right upper quadrant (RUQ), paracolic gutter and pelvis). If fluid was more than minimal (2 mm in depth) in the RUQ or LUQ, 2 points instead of 1 were assigned. Floating loops of the bowel were given 2 points. Scores range from 0 to 8 points. They found that where patients had a score of 3 or more, sensitivity for quantifying haemoperitineum as greater than 1000 ml compared to operative findings was 81% and specificity 71%. Of those with a score greater or equal to 3, 96% required laparotomy and of those with a score less than 3, 38% required surgery.

McKenney et al.[68] developed a system based on examining the abdomen in five areas. These were the right subphrenic and subhepatic spaces, the left subphrenic and perisplenic areas and the pelvis. If the bladder was empty, fluid was instilled to improve the views. The deepest pocket of free fluid was measured in centimetres in the anteroposterior plane and given an equivalent score. A further point was added for fluid found in any other of the remaining four areas (e.g., 3 cm in the subhepatic space = 3 points, additional fluid in perisplenic space = 1 point and fluid in pelvis = 1 point; total score = 3 + 1 + 1 = 5 points). Of the patients, 85% with scores of 3 or over, and 15% with a score less than 3 required laparotomy.

Training required

The exact amount of training required to be able to perform the FAST is a question that remains to be clearly answered. It is a controversial area and many people have a vested interest, and consequently recommendations range from a brief course and 10 supervised scans to 3 years' training and more than 500 scans.

Practice tips

- Learning curve for FAST
  - Sensitivity improves rapidly to 25–50 scans.
  - Then continues to improve slowly to 200 scans then reaches a plateau.
- Training should include
  - A course with theoretical and practical components,
  - Supervised scans,
  - Exposure to adequate number and variety of positive scans,
    - Even if these are simulated (e.g., peritoneal dialysis patients)
  - Standardised assessment to assess knowledge and skills
    - Objective structured clinical examinations (OSCEs) are very useful.

It seems that for a simple FAST examination, there is a learning curve that is relatively steep for the first 25–50 scans with a relatively rapid improvement in sensitivity throughout this period.[26,33,69,70] Ma et al. recently demonstrated that after 12 months (or 35 examinations) the accuracy of EM residents novice to use of ultrasound approximated previously reported accuracy rates.[71] The learning curve becomes more

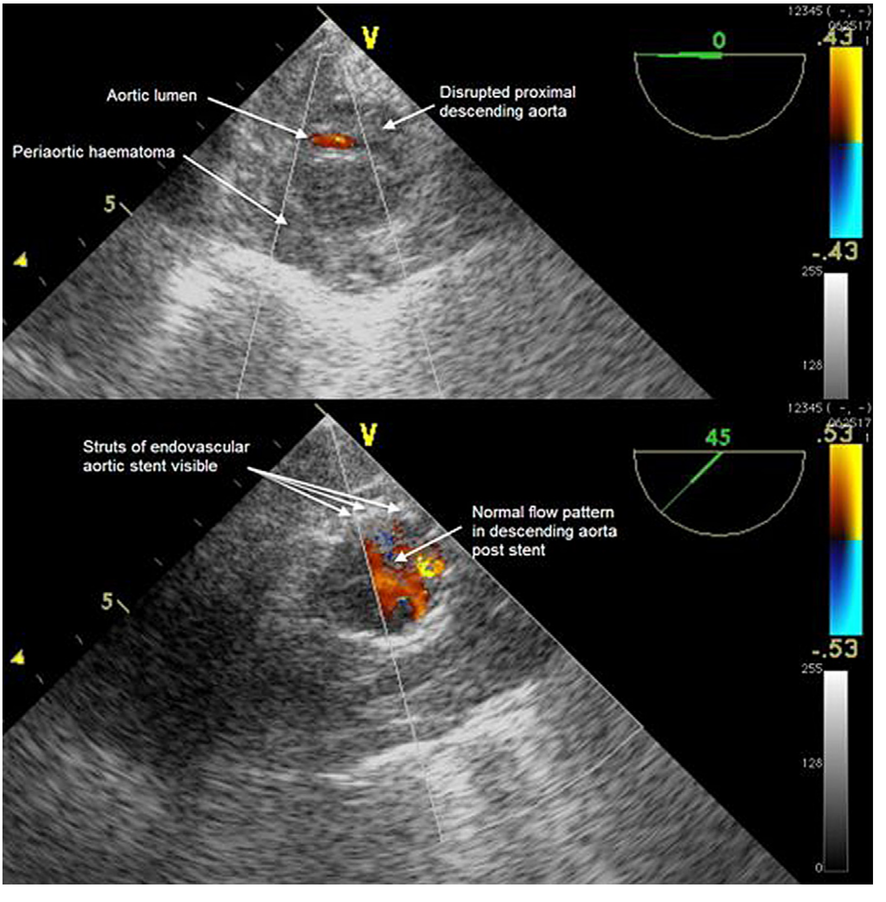

Fig. 8. Transoesophageal echocardiography images of the proximal descending aorta showing disruption and near complete occlusion of the lumen (upper panel). The lumen has been restored by placement of an endoluminal stent (lower panel).

gradual until 200 scans have been performed. Little measured improvement in sensitivity or specificity occurs after 200 scans have been performed.[33] Training does not simply depend on the number of FAST examinations. An essential element is to see a variety of positive scans. The positive FAST rate is quoted as being 9–13%[25,72,73]; however, as the threshold for FAST examination decreases it may be getting lower. In addition, fluid may collect in different areas with each positive scan. An individual may perform 50 scans, but only have five positive scans, none of which showed free fluid in the LUQ or pelvis – clearly indicating inadequate training. To overcome this, training on continuous ambulatory peritoneal dialysis (CAPD) patients or patients with ascites simulating haemoperitoneum is very useful. Gracias showed that sensitivity improved from 43% to 87% after a 2 hour practical session with dialysis patients.[34]

Comprehensive ultrasound examination along with the use of contrast agents takes considerably more experience. McGahan and colleagues suggest that trauma sonography has a definite learning curve and should only be performed by ultrasound technologists with more than 3 years' experience, and interpreted by radiologists with more than 3 years' training in sonographic techniques.[64]

Ultrasound is definitely operator dependent and expertise increases with experience. It has now been shown in the literature that with relatively little training and experience, operators can reliably detect large volumes of free fluid, and this is extremely useful in the unstable trauma patient. As long as users with limited experience understand the limitations of ultrasound in this setting and follow guidelines appropriately, management of trauma patients will be improved by ultrasound. For more advanced ultrasound use, however, including attempting to exclude injury rather than just confirm the presence of free fluid, and definitely if contrast agents are to be used, far more training is required.

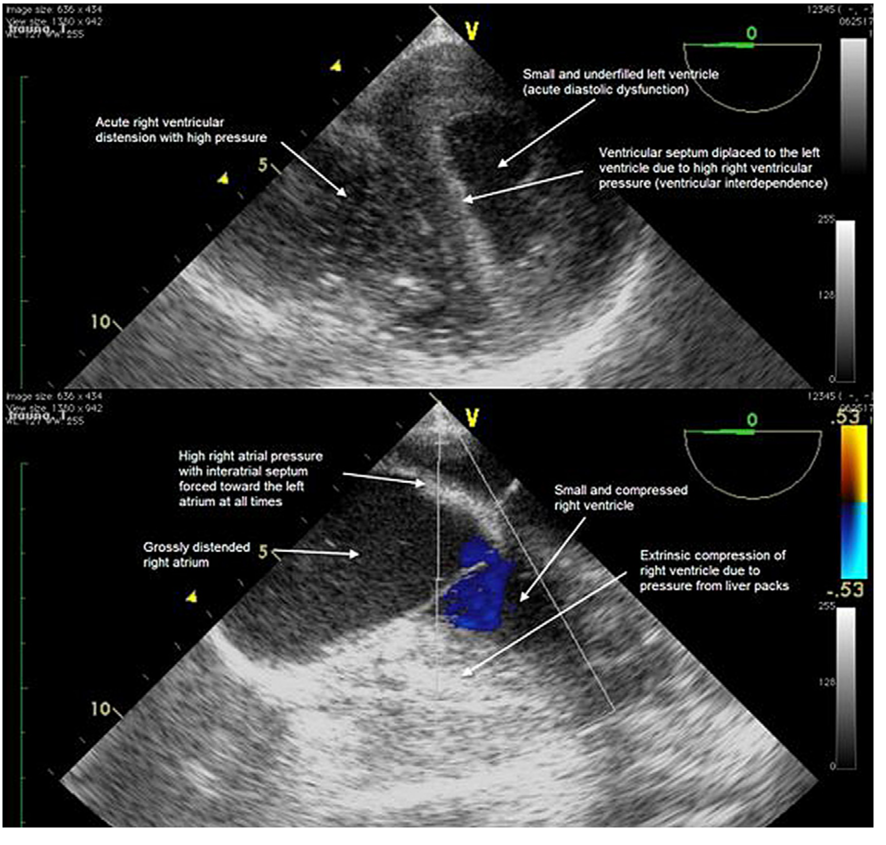

Fig. 9. Transoesophageal echocardiography images of right ventricular compression caused by surgical packs placed around the liver. The compression has also "squashed" the left ventricle, inducing acute left ventricular diastolic dysfunction.

Use of trans-oesophageal echocardiography in trauma

The key advantage of trans-oesophageal echocardiography (TOE) in major trauma cases relates to the dual capability of diagnostic information and sophisticated haemodynamic monitoring. The most important diagnostic aspect to TOE relates to the diagnosis of the 'haemodynamic state'. This guides the use of fluid and vasoactive medications. In young people with presumed normal ventricular function, the key differentiation is between hypovolaemia and a vasodilated state. In older patients with diastolic dysfunction or valvular pathology, these crucially need to be differentiated from hypovolaemia and the vasodilated state. It is not possible to adequately differentiate these different haemodynamic states with invasive pressure monitoring alone. Additionally, the trans-oesophageal probe remains in the oesophagus throughout the case, allowing for immediate assessment of the response to treatment.

Specific diagnostic information relating to the heart and great vessels is also possible, particularly cardiac tamponade, segmental wall motion of abilities of the left ventricle or right ventricle, right ventricular dysfunction, valvular pathologies or great vessel injuries such as disruption of the proximal descending aorta. TOE has a high sensitivity and specificity for aortic transection, though the imaging may be obscured by extensive peri-aortic haematoma. An example of aortic transection at the level of the left subclavian artery with later endoluminal stent placement is shown in Fig. 8, and compression of the right ventricle from liver packs is shown in Fig. 9.

Research agenda and other challenges

- Training and competence in ultrasound
  - How to minimise inter-operator variability
  - How to ensure adequate training and competence
- Contrast agent use in detecting solid-organ injury in trauma
  - Liver and spleen
- Best technique to quantify free fluid detected on a FAST scan

To summarise, use of ultrasound in the trauma scenario is now widely used and accepted. There are numerous roles both in the triage and resuscitation phase and later in the detailed assessment of a patient where the use of ultrasound is invaluable.

The major area concerning both clinicians and radiologists is how to ensure adequate training and competence in what is such a user- and experience-dependent tool, and this is the primary challenge currently.

References

1. Kristensen JK, Buemann B & Kuhl E. Ultrasonic scanning in the diagnosis of splenic haematomas. *Acta Chirurgica Scandinavica* 1971; **137**(7)**:** 653–657.
2. Asher WM, Parvin S, Virgillo RW & Haber K. Echographic evaluation of splenic injury after blunt trauma. *Radiology* 1976 Feb; **118**(2)**:** 411–415.
3. Halbfass HJ, Wimmer B, Hauenstein K & Zavisic D. Ultrasonic diagnosis of blunt abdominal injuries. *Fortschritte der Medizin* 1981 Nov 5; **99**(41)**:** 1681–1685.
4. Aufschnaiter M & Kofler H. Sonographic acute diagnosis in polytrauma. *Aktuelle Traumatologie* 1983 Apr; **13**(2)**:** 55–57.
5. Hoffman R, Pohlemann T & Wipperman B. Management of blunt abdominal trauma using sonography. *Unfallchirig* 1989; **92:** 471.
6. Wening JV. Evaluation of ultrasound, lavage, and computed tomography in blunt abdominal trauma. *Surgical Endoscopy* 1989; **3**(3)**:** 152–158.

*7. Rozycki GS, Ochsner MG, Schmidt JA et al. A prospective study of surgeon-performed ultrasound as the primary adjuvant modality for injured patient assessment. *The Journal of Trauma* 1995 Sep; **39**(3)**:** 492–498. discussion 8–500.

*8. Melniker LA, Leibner E, McKenney MG et al. Randomized controlled clinical trial of point-of-care, limited ultrasonography for trauma in the emergency department: the first sonography outcomes assessment program trial. *Annals of Emergency Medicine* 2006 Sep; **48**(3)**:** 227–235.

9. Ollerton JE, Sugrue M, Balogh Z et al. Prospective study to evaluate the influence of FAST on trauma patient management. *The Journal of Trauma* 2006 Apr; **60**(4)**:** 785–791.
10. Wherrett LJ, Boulanger BR, McLellan BA et al. Hypotension after blunt abdominal trauma: the role of emergent abdominal sonography in surgical triage. *The Journal of Trauma* 1996 Nov; **41**(5)**:** 815–820.
*11. Stengal D, Bauwens K, Sehouli J & Rademacher G. Emergency Ultrasound-based algorithms for diagnosing blunt abdominal trauma. *Cochrane Database of Systematic Reviews (Online)* 2009; (1).
12. Rozycki GS, Ochsner MG, Jaffin JH & Champion HR. Prospective evaluation of surgeons' use of ultrasound in the evaluation of trauma patients. *The Journal of Trauma* 1993 Apr; **34**(4)**:** 516–526. discussion 26–7.
13. Taylor GA & Sivit CJ. Posttraumatic peritoneal fluid: is it a reliable indicator of intraabdominal injury in children? *Journal of Pediatric Surgery* 1995 Dec; **30**(12)**:** 1644–1648.
14. Beck-Razi N & Gaitini D. Focused assessment with sonography for trauma. *Ultrasound Clinics* 2008; **3:** 23–31.
*15. Beck-Razi N, Fischer D, Michaelson M et al. The utility of focused assessment with sonography for trauma as a triage tool in multiple-casualty incidents during the second Lebanon war. *Journal of Ultrasound in Medicine* 2007 Sep; **26**(9)**:** 1149–1156.
16. Ma OJ, Mateer JR, Blaivas M, editors. *Emergency ultrasound*. 2 edn. New York: McGraw Hill; 2002.
17. Branney SW, Moore EE, Cantrill SV et al. Ultrasound based key clinical pathway reduces the use of hospital resources for the evaluation of blunt abdominal trauma. *The Journal of Trauma* 1997 Jun; **42**(6)**:** 1086–1090.
18. Boulanger BR, Kearney PA, Tsuei B & Ochoa JB. The routine use of sonography in penetrating torso injury is beneficial. *The Journal of Trauma* 2001 Aug; **51**(2)**:** 320–325.
19. Asensio JA, Arroyo Jr. H, Veloz W et al. Penetrating thoracoabdominal injuries: ongoing dilemma-which cavity and when? *World Journal of Surgery* 2002 May; **26**(5)**:** 539–543.
*20. Korner M, Krotz MM, Degenhart C et al. Current role of emergency US in patients with major trauma. *Radiographics* 2008 Jan–Feb; **28**(1)**:** 225–242.
21. Miller MT, Pasquale MD, Bromberg WJ et al. Not so FAST. *The Journal of Trauma* 2003 Jan; **54**(1)**:** 52–59. discussion 9–60.
22. Kimura A & Otsuka T. Emergency center ultrasonography in the evaluation of hemoperitoneum: a prospective study. *The Journal of Trauma* 1991 Jan; **31**(1)**:** 20–23.
23. Rothlin MA, Naf R, Amgwerd M et al. Ultrasound in blunt abdominal and thoracic trauma. *The Journal of Trauma* 1993 Apr; **34**(4)**:** 488–495.
24. Ma OJ, Kefer MP, Mateer JR & Thoma B. Evaluation of hemoperitoneum using a single- vs multiple-view ultrasonographic examination. *Academic Emergency Medicine* 1995 Jul; **2**(7)**:** 581–586.
25. Ma OJ, Mateer JR, Ogata M et al. Prospective analysis of a rapid trauma ultrasound examination performed by emergency physicians. *The Journal of Trauma* 1995 Jun; **38**(6)**:** 879–885.
26. Shackford SR, Rogers FB, Osler TM et al. Focused abdominal sonogram for trauma: the learning curve of nonradiologist clinicians in detecting hemoperitoneum. *The Journal of Trauma* 1999 Apr; **46**(4)**:** 553–562. discussion 62–4.
27. Hoffmann R, Nerlich M, Muggia-Sullam M et al. Blunt abdominal trauma in cases of multiple trauma evaluated by ultrasonography: a prospective analysis of 291 patients. *The Journal of Trauma* 1992 Apr; **32**(4)**:** 452–458.
28. Tso P, Rodriguez A, Cooper C et al. Sonography in blunt abdominal trauma: a preliminary progress report. *The Journal of Trauma* 1992 Jul; **33**(1)**:** 39–43. discussion -4.
29. Lentz KA, McKenney MG, Nunez Jr. DB & Martin L. Evaluating blunt abdominal trauma: role for ultrasonography. *Journal of Ultrasound in Medicine* 1996 Jun; **15**(6)**:** 447–451.
30. McElveen TS & Collin GR. The role of ultrasonography in blunt abdominal trauma: a prospective study. *The American Surgeon* 1997 Feb; **63**(2)**:** 184–188.
31. Rozycki GS, Feliciano DV, Ochsner MG et al. The role of ultrasound in patients with possible penetrating cardiac wounds: a prospective multicenter study. *The Journal of Trauma* 1999 Apr; **46**(4)**:** 543–551. discussion 51–2.
32. Bode PJ, Edwards MJ, Kruit MC & van Vugt AB. Sonography in a clinical algorithm for early evaluation of 1671 patients with blunt abdominal trauma. *AJR American Journal of Roentgenology* 1999 Apr; **172**(4)**:** 905–911.
33. Gracias VH, Frankel HL, Gupta R et al. Defining the learning curve for the Focused Abdominal Sonogram for Trauma (FAST) examination: implications for credentialing. *The American Surgeon* 2001 Apr; **67**(4)**:** 364–368.
34. Gracias VH, Frankel H, Gupta R et al. The role of positive examinations in training for the focused assessment sonogram in trauma (FAST) examination. *The American Surgeon* 2002 Nov; **68**(11)**:** 1008–1011.
35. Akgur FM, Aktug T, Olguner M et al. Prospective study investigating routine usage of ultrasonography as the initial diagnostic modality for the evaluation of children sustaining blunt abdominal trauma. *The Journal of Trauma* 1997 Apr; **42**(4)**:** 626–628.
36. Brown MA, Sirlin CB, Farahmand N et al. Screening sonography in pregnant patients with blunt abdominal trauma. *Journal of Ultrasound in Medicine* 2005 Feb; **24**(2)**:** 175–181. quiz 83–84.
37. Clevert DA, Weckbach S, Minaifar N et al. Contrast-enhanced ultrasound versus MS-CT in blunt abdominal trauma. *Clinical Hemorheology and Microcirculation* 2008; **39**(1–4)**:** 155–169.
38. Thorelius L. Emergency real-time contrast-enhanced ultrasonography for detection of solid organ injuries. *European Radiology* 2007 Dec; **17**(Suppl. 6)**:** F107–F111.
39. Valentino M, Serra C, Pavlica P & Barozzi L. Contrast-enhanced ultrasound for blunt abdominal trauma. *Seminars in Ultrasound, CT, and MR* 2007 Apr; **28**(2)**:** 130–140.
40. Valentino M, Serra C, Zironi G et al. Blunt abdominal trauma: emergency contrast-enhanced sonography for detection of solid organ injuries. *AJR American Journal of Roentgenology* 2006 May; **186**(5)**:** 1361–1367.
41. Karrel R, Shaffer MA & Franaszek JB. Emergency diagnosis, resuscitation, and treatment of acute penetrating cardiac trauma. *Annals of Emergency Medicine* 1982 Sep; **11**(9)**:** 504–517.
42. Demetriades D & van der Veen BW. Penetrating injuries of the heart: experience over two years in South Africa. *The Journal of Trauma* 1983 Dec; **23**(12)**:** 1034–1041.
43. Mandavia DP & Joseph A. Bedside echocardiography in chest trauma. *Emergency Medicine Clinics of North America* 2004 Aug; **22**(3)**:** 601–619.
44. Plummer D, Brunette D, Asinger R & Ruiz E. Emergency department echocardiography improves outcome in penetrating cardiac injury. *Annals of Emergency Medicine* 1992 Jun; **21**(6)**:** 709–712.

45. Meyer DM, Jessen ME & Grayburn PA. Use of echocardiography to detect occult cardiac injury after penetrating thoracic trauma: a prospective study. *The Journal of Trauma* 1995 Nov; **39**(5): 902–907. discussion 7–9.
46. Sisley AC, Rozycki GS, Ballard RB et al. Rapid detection of traumatic effusion using surgeon-performed ultrasonography. *The Journal of Trauma* 1998 Feb; **44**(2): 291–296. discussion 6–7.
47. Schiavone WA, Ghumrawi BK, Catalano DR et al. The use of echocardiography in the emergency management of non-penetrating traumatic cardiac rupture. *Annals of Emergency Medicine* 1991 Nov; **20**(11): 1248–1250.
48. Powell MA & Lucente FC. Diagnosis and treatment of blunt cardiac rupture. *The West Virginia Medical Journal* 1997 Mar–Apr; **93**(2): 64–67.
49. Brathwaite CE, Rodriguez A, Turney SZ et al. Blunt traumatic cardiac rupture. A 5-year experience. *Annals of Surgery* 1990 Dec; **212**(6): 701–704.
50. Rozycki GS, Pennington SD & Feliciano DV. Surgeon-performed ultrasound in the critical care setting: its use as an extension of the physical examination to detect pleural effusion. *The Journal of Trauma* 2001 Apr; **50**(4): 636–642.
51. Ma OJ & Mateer JR. Trauma ultrasound examination versus chest radiography in the detection of hemothorax. *Annals of Emergency Medicine* 1997 Mar; **29**(3): 312–315. discussion 5–6.
52. Brooks A, Davies B, Smethhurst M & Connolly J. Emergency ultrasound in the acute assessment of haemothorax. *Emergency Medicine Journal* 2004 Jan; **21**(1): 44–46.
53. Abboud PA & Kendall J. Emergency department ultrasound for hemothorax after blunt traumatic injury. *The Journal of Emergency Medicine* 2003 Aug; **25**(2): 181–184.
*54. Soldati G, Testa A, Sher S et al. Occult traumatic pneumothorax: diagnostic accuracy of lung ultrasonography in the emergency department. *Chest* 2008 Jan; **133**(1): 204–211.
55. Rowan KR, Kirkpatrick AW, Liu D et al. Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT–initial experience. *Radiology* 2002 Oct; **225**(1): 210–214.
56. Blaivas M, Lyon M & Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Academic Emergency Medicine* 2005 Sep; **12**(9): 844–849.
57. Coley BD, Mutabagani KH, Martin LC et al. Focused abdominal sonography for trauma (FAST) in children with blunt abdominal trauma. *The Journal of Trauma* 2000 May; **48**(5): 902–906.
58. Soudack M, Epelman M, Maor R et al. Experience with focused abdominal sonography for trauma (FAST) in 313 pediatric patients. *Journal of Clinical Ultrasound* 2004 Feb; **32**(2): 53–61.
59. Patel JC & Tepas 3rd JJ. The efficacy of focused abdominal sonography for trauma (FAST) as a screening tool in the assessment of injured children. *Journal of Pediatric Surgery* 1999 Jan; **34**(1): 44–47. discussion 52–4.
*60. Akgur FM, Tanyel FC, Akhan O et al. The place of ultrasonographic examination in the initial evaluation of children sustaining blunt abdominal trauma. *Journal of Pediatric Surgery* 1993 Jan; **28**(1): 78–81.
*61. Holmes JF, Gladman A & Chang CH. Performance of abdominal ultrasonography in pediatric blunt trauma patients: a meta-analysis. *Journal of Pediatric Surgery* 2007 Sep; **42**(9): 1588–1594.
62. Luks FI, Lemire A, St-Vil D et al. Blunt abdominal trauma in children: the practical value of ultrasonography. *The Journal of Trauma* 1993 May; **34**(5): 607–610. discussion 10–1.
63. Branney SW, Wolfe RE, Moore EE et al. Quantitative sensitivity of ultrasound in detecting free intraperitoneal fluid. *The Journal of Trauma* 1995 Aug; **39**(2): 375–380.
64. McGahan JP, Rose J, Coates TL et al. Use of ultrasonography in the patient with acute abdominal trauma. *Journal of Ultrasound in Medicine* 1997 Oct; **16**(10): 653–662. quiz 63–4.
65. Abrams BJ, Sukumvanich P, Seibel R et al. Ultrasound for the detection of intraperitoneal fluid: the role of Trendelenburg positioning. *The American Journal of Emergency Medicine* 1999 Mar; **17**(2): 117–120.
66. Scalea TM, Rodriguez A, Chiu WC et al. Focused Assessment with Sonography for Trauma (FAST): results from an international consensus conference. *The Journal of Trauma* 1999 Mar; **46**(3): 466–472.
67. Huang MS, Liu M, Wu JK et al. Ultrasonography for the evaluation of hemoperitoneum during resuscitation: a simple scoring system. *The Journal of Trauma* 1994 Feb; **36**(2): 173–177.
68. McKenney KL, McKenney MG, Cohn SM et al. Hemoperitoneum score helps determine need for therapeutic laparotomy. *The Journal of Trauma* 2001 Apr; **50**(4): 650–654. discussion 4–6.
69. Rose JS. Ultrasound in abdominal trauma. *Emergency Medicine Clinics of North America* 2004 Aug; **22**(3): 581–599. vii.
70. Thomas B, Falcone RE, Vasquez D et al. Ultrasound evaluation of blunt abdominal trauma: program implementation, initial experience, and learning curve. *The Journal of Trauma* 1997 Mar; **42**(3): 384–388. discussion 8–90.
*71. Ma OJ, Gaddis G, Norvell JG & Subramanian S. How fast is the focused assessment with sonography for trauma examination learning curve? *Emergency Medicine Australasia* 2008 Feb; **20**(1): 32–37.
72. Dolich MO, McKenney MG, Varela JE et al. 2,576 ultrasounds for blunt abdominal trauma. *The Journal of Trauma* 2001 Jan; **50**(1): 108–112.
*73. Rozycki GS, Ballard RB, Feliciano DV et al. Surgeon-performed ultrasound for the assessment of truncal injuries: lessons learned from 1540 patients. *Annals of Surgery* 1998 Oct; **228**(4): 557–567.