Abdominal and Cardiac Evaluation with Sonography in Shock (ACES): an approach by emergency physicians for the use of ultrasound in patients with undifferentiated hypotension

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ABSTRACT

Background: Non-traumatic undifferentiated hypotension is a common critical presentation in the emergency department. In this group of patients, early diagnosis and goal-directed therapy is essential for an optimal outcome. The usefulness of focused bedside ultrasound is reviewed and a protocol for Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) is proposed.

Methods: The protocol consists of six windows including cardiac, peritoneal, pleural, inferior vena cava and aortic views, and aims to shorten the time period taken to establish a diagnosis and hence to deliver the most appropriate goal-directed therapy. Its use in seven case examples is described.

Results: In all cases the ACES protocol helped in guiding the initial management while further information was obtained.

Conclusion: The six-view ACES protocol is a useful adjunct to clinical examination in patients with undifferentiated hypotension in the emergency department. A prospective randomised trial or multicentre database/registry is needed to investigate the validity and impact of this protocol on the early diagnosis and management of hypotensive patients.

Bedside, focused or point of care ultrasound is becoming an established technique within emergency medicine and critical care to answer time-dependent focused clinical questions. It has some advantages for the physician over traditional imaging modalities, particularly in the setting of acute illness; it is safe, rapid, non-invasive and comes to the patient's bedside. Bedside sonography is not a complete radiological investigation but, rather, an extension of the clinical examination to rule in or rule out key diagnoses in specific clinical settings.[1] Point of care ultrasound is geared to addressing highly time-dependent and focused questions and, in general, most focused scans become more obviously positive as the patient becomes increasingly unwell.

Hypotension evident in the emergency department is a predictor of inhospital mortality.[2] Protocols for goal-directed sonography have been proposed and been shown to result in fewer viable diagnostic aetiologies and a more accurate physician impression of final diagnosis in the evaluation of non-traumatic symptomatic undifferentiated hypotension in adult patients.[3 4] In such hypotensive patients, the rapid non-invasive assessment of intravascular filling pressures and identification of possible aetiologies for shock facilitates early goal-directed therapy. It is important that the clinician does not delay supportive therapy in pursuit of understanding the aetiology of a given presentation.

In view of these requirements, we propose a rapid focused ultrasound protocol consisting of six views (fig 1). Many emergency physicians are already familiar with several of these views from the FAST (Focused Assessment with Sonography in Trauma) protocol and also from emergency department ultrasound assessment of the abdominal aorta. The Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) protocol consists of:

1. A focused view of the heart
   - The initial view should be a transverse subxiphoid four-chamber view looking at general overall contractility, right and left ventricular chamber size and contractility, and for the presence of pericardial fluid with evidence of tamponade. This view may be obtained with either a standard curvilinear or phased array transducer.
   - Should a subxiphoid view be unobtainable, a parasternal long axis or an apical four-chamber view can be used. These will require a micro-convex or small footprint phased array cardiac transducer.
2. An inferior vena cava (IVC) diameter and collapse index, measured using the longitudinal subxiphoid window looking at the IVC as it passes posterior to the liver and into the heart.
3. A focused assessment of the abdominal aorta obtained by a sliding transverse view from the diaphragm to its bifurcation.
4. A right upper quadrant hepatorenal/lung base view looking for free peritoneal or pleural fluid.
5. A left upper quadrant splenorenal/lung base view, again looking for peritoneal or pleural free fluid.
6. A transverse pelvic view looking at bladder volume and for free pelvic fluid.

CASE EXAMPLES

The following typical case examples demonstrate the potential usefulness of the ACES protocol in

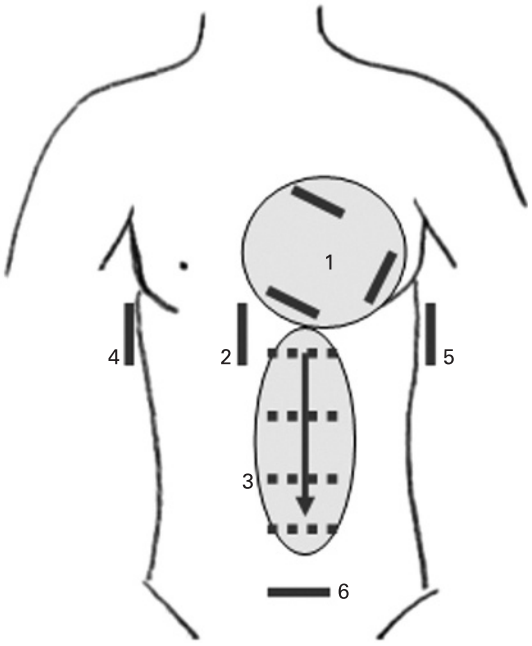

Figure 1 The Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) protocol: ultrasound windows consist of (1) one or more cardiac views, (2) an inferior vena cava view, (3) a screen of the abdominal aorta, (4) right and (5) left flank views for pleural and peritoneal fluid, and (6) a pelvic view for bladder size and free fluid.

determining factors such as cardiac function, fluid status of the patient and ruling in key diagnoses.

Case 1

A 40-year-old man presents to the emergency department complaining of increasing breathlessness without chest pain over 2 weeks. He had previously been well. On examination he has quiet heart sounds, his JVP is raised at 6 cm and his blood pressure is 85/62 mm Hg. A chest radiograph shows a globular enlarged heart and an ECG demonstrates sinus tachycardia only. Cardiac tamponade is suspected. However, an ACES scan shows an enlarged hypodynamic dilated left ventricle. The remaining views including the IVC collapse index are normal. A diagnosis of dilated cardiomyopathy is made and he is referred to the on-call cardiology services.

Case 2

An EMS pre-alert call warns of a 62-year-old man presenting with hypotension and epigastric pain with a suspected abdominal aortic aneurysm. On arrival at the emergency department he is hypotensive with a tachycardia of 110 and a systolic blood pressure of 74 mm Hg. Initial resuscitation is instituted and an ACES scan performed. This scan reveals a vigorously contracting heart with a hyperdynamic left ventricle and normal right ventricular size with no pericardial effusion. Examination of his IVC shows an underfilled vessel with raised collapse index (fig 2). He has no evidence of free fluid or aortic aneurysm on further views. He receives a further fluid challenge and is treated as a case of probable sepsis. An internal jugular line is placed under ultrasound guidance and a chest radiograph confirms right upper lobe pneumonia.

Case 3

A 49-year-old man presents with acute dyspnoea having complained of a sore swollen leg for 24 h. On arrival he is extremely distressed and cyanosed with a respiratory rate of 36, heart rate of 120 and a blood pressure of 85/50 mm Hg. His oxygen saturations on high-flow oxygen are 83%. The chest radiograph is clear, an ECG demonstrates sinus tachycardia and a D-dimer assay result is pending. His blood pressure does not improve after an intravenous fluid bolus. An ACES protocol is performed which shows a dilated right ventricle (fig 3) and a reduced collapse index of his IVC which is dilated. No other positive findings are noted and a diagnosis of pulmonary embolism is made. He receives thrombolysis with improvement in his signs and symptoms.

Case 4

An 81-year-old woman complains of sudden onset of chest pain. She had a collapse in the ambulance with a witnessed seizure. On arrival in the emergency department she is comatose and

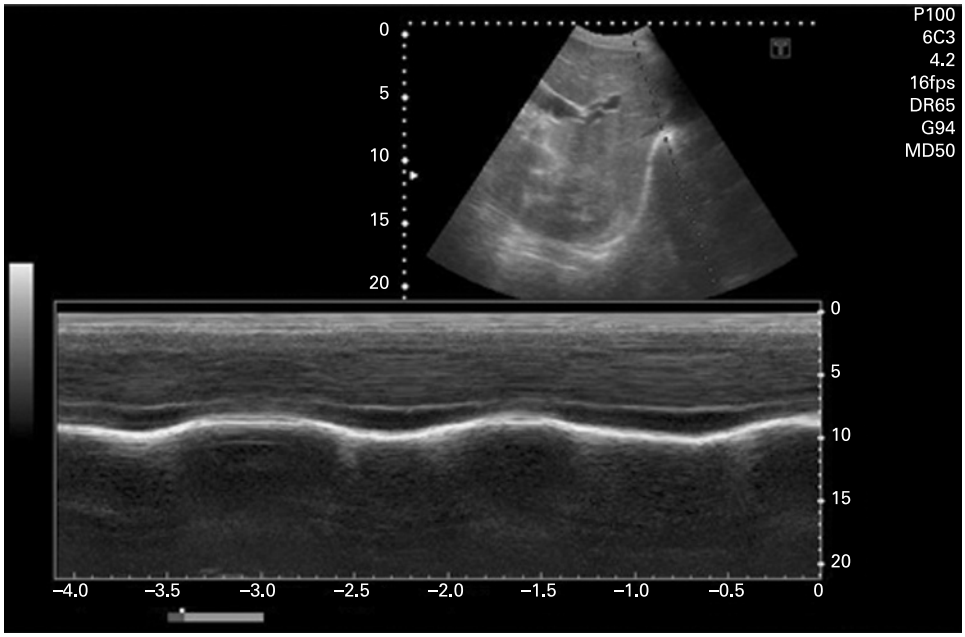

Figure 2 Subcostal longitudinal view of the inferior vena cava with collapse index measured in M mode.

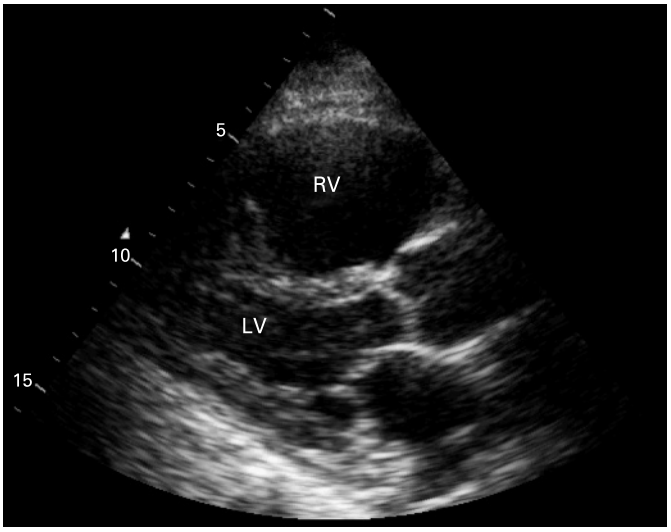

Figure 3 Focused cardiac scan (parasternal long-axis view) showing a dilated right ventricle (RV). LV, left ventricle.

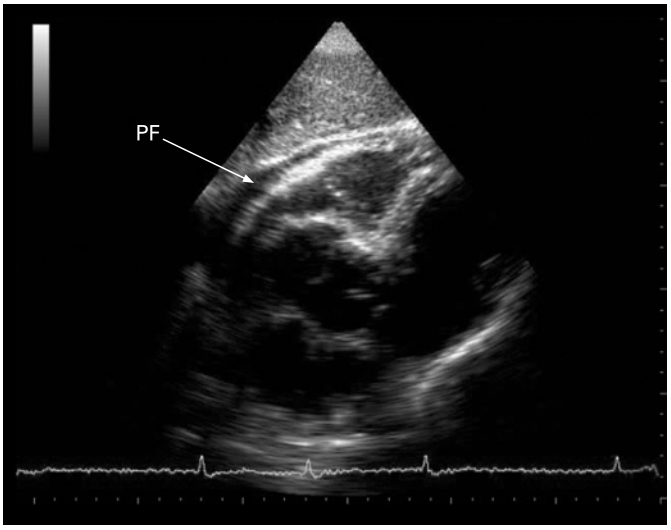

Figure 4 Focused cardiac scan (subcostal view) showing pericardial fluid (PF).

hypotensive with a systolic blood pressure of 55 mm Hg in both arms. She is generally mottled. Infusion of 2 litres crystalloid fails to significantly improve her haemodynamic or neurological status. An ACES protocol scan shows a pericardial effusion and a dilated IVC with reduced collapse index (fig 4). Further focused cardiac views reveal a dilated aortic root and visible dissection flap in the long axis parasternal view. A diagnosis of type A aortic dissection with tamponade is made and she is referred to cardiothoracic services.

Case 5

A 22-year-old woman complains of sudden onset of lower abdominal pain which was associated with a collapse. On arrival at the emergency department she is hypotensive and has generalised guarding over her lower abdomen. The ACES protocol shows a vigorously contracting heart with no tamponade or effusion. Her IVC collapse index is >50%. The other positive sonographic finding is a large volume of free fluid in her right and left upper quadrant and pelvic scans which, in combination with a positive pregnancy test, leads to a diagnosis of ruptured ectopic pregnancy and urgent laparotomy (fig 5).

Case 6

An 81-year-old man is brought to the department with a systolic blood pressure of 65 mm Hg, looking pale. There is a mass in his upper abdomen but it is difficult to determine if it is pulsatile due to his low blood pressure. Initial resuscitation is started and a focused scan shows a large abdominal aortic aneurysm (fig 6). Resuscitation is limited to a permissive level such that the patient is conscious and coherent and he is rapidly transferred to the regional vascular unit to undergo surgical repair.

Case 7

A 22-year-old obese man with a past history of significant massive pulmonary embolism presents with a 3-day history of significant haemoptysis. He is not currently anticoagulated. He is initially hypotensive (75/40 mm Hg) with evidence of air hunger. He responds to initial fluid resuscitation. A chest radiograph shows a small filling defect, possibly infarct or infection. He is too large for the CT scanner. Thrombolysis is being considered but an ACES scan reveals an underfilled IVC and normal right ventricular size. There is a generally hyperdynamic heart and no evidence of femoral thrombosis. Further fluid boluses improve his condition and subsequent investigation reveals sepsis secondary to pneumonia as a source for his presentation.

DISCUSSION

The ACES protocol allows a structured approach to the sonographic assessment of the patient with undifferentiated hypotension. It uses windows with which many emergency physicians will already be familiar, together with a standard view of the IVC. The dual aims of the ACES bedside ultrasound protocol are to estimate right-sided filling pressures and to identify a likely aetiology for hypotension when there is none evident from the initial primary survey (table 1). This allows the physician to begin to address the likely cause prior to more advanced monitoring and investigation being available.

The major categories for hypotension are traditionally grouped as:

- Hypovolaemia.
- Obstructive (tamponade/pulmonary embolism).
- Cardiogenic.
- Distributive (septic).

Hypovolaemia

The ACES protocol helps with confirmation of a hypovolaemic state as well as identification of possible causes. The IVC can be visualised using either a cardiac or abdominal probe with a longitudinal view taken in the subxiphoid position. The IVC is identified lying posterior to the liver receiving hepatic veins ventrally before it passes through the diaphragm and into the right atrium. M mode measurements of minimal and maximal diameter can be made across the proximal IVC. In healthy blood donors the measurement of the IVC diameter is a reliable indicator of blood loss, with even small amounts (450 ml) causing a mean decrease in IVC diameter of 5 mm.[5]

In a haemodynamically normal, spontaneously ventilating patient, the IVC collapses slightly on inspiration. This is reversed in a mechanically ventilated patient where there is an increased diameter in the abdominal IVC during inspiration.

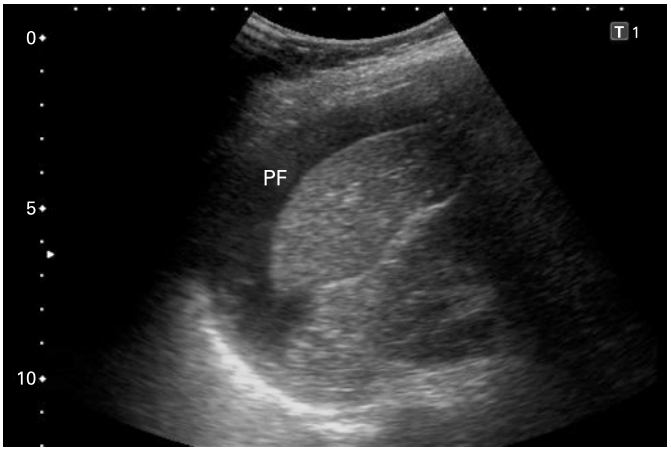

Figure 5 Left upper quadrant view showing haemoperitoneum/peritoneal fluid (PF).

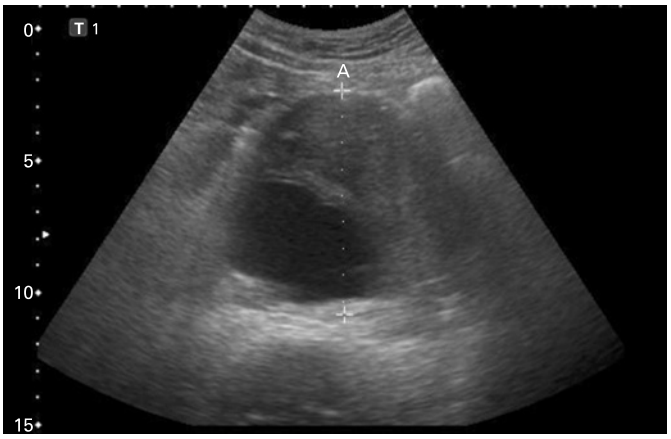

Figure 6 Aortic scan showing an 8-cm abdominal aortic aneurysm (between markers).

Changes in diameter correlate with changes in intrathoracic and intra-abdominal pressure. A collapse index is calculated as the change in diameter between inspiration and expiration divided by the maximal diameter (table 2). It may be more useful to measure trends of IVC diameter and collapsibility in response to fluid resuscitation; however, there is evidence for cut-off values which can indicate an underfilled or overfilled status. A maximal IVC diameter of <2 cm with inspiratory collapse of more than 40–50% indicates a right atrial pressure of <10 mm Hg. Conversely, a diameter of >2 cm with collapse of <40–50% suggests a pressure of >10 mm Hg.[6 7]

It is important to interpret these IVC signs within the clinical context and not as a definitive measure of right atrial pressure or intravascular volume, as there is a lack of high level evidence in the setting of critical illness. As such, IVC size and collapse must be considered in association with ventricular size, wall motion and the presence or absence of pericardial fluid (see below). A small chamber size with hyperdynamic wall motion on the cardiac view is consistent with hypovolaemia. Potential causes of hypovolaemia can be diagnosed by further ultrasound views of the right and left flanks and pelvis, aiming to detect significant haemoperitoneum or haemothorax (fig 3), and of the abdominal aorta to identify the presence of abdominal aortic aneurysm (fig 6).

Obstructive

The ACES protocol aims to identify not only the presence of a pericardial effusion, but any associated dilation of the IVC indicative of tamponade. In the context of critical illness, pericardial effusions can be a common finding (up to 20% in high-risk patients), making it essential to look for evidence of tamponade. There should be a reduced IVC collapse index, and it may be possible to identify collapse of the right side of the heart during diastole (fig 4). This has been demonstrated in a series of patients with traumatic cardiac tamponade.[8]

The ACES protocol also aims to identify right ventricular dilation and hypokinesis with paradoxical septal motion (fig 5). As a simple guide, the right ventricle is normally 60% of the left ventricle. If the right ventricular diameter is approaching or greater than that of the left ventricle, there is significant enlargement. IVC distension or non-collapsibility, as well as bulging of the septum into the left ventricle, may also be noted.

Table 1 Abdominal and Cardiac Evaluation with Sonography in Shock (ACES) protocol: possible ultrasound findings in shock

Category of shock	Cardiac	IVC	Aorta	Peritoneal fluid/blood	Pleural fluid/blood
Septic	Hyperdynamic left ventricle	Narrow IVC	Normal	?Surgical/gynaecological sepsis	?Pneumonia
	Hypodynamic in late sepsis	Collapses			
Cardiogenic	Hypodynamic left ventricle	Normal	Normal	Normal	Normal
Hypovolaemic	Hyperdynamic left ventricle	Narrow IVC	?AAA	?Spontaeous splenic rupture	Normal
		Collapses		?Perforated viscous	
				?Gynaecological bleed	
Obstructive (cardiac tamponade)	Pericardial fluid	Variable IVC	Normal	Normal	Normal
	Diastolic collapse right ventricle	Minimal collapse			
Obstructive (pulmonary embolus)	Dilated right ventricle	Dilated IVC	Normal	Normal	Normal
		Minimal collapse			

AAA, abdominal aortic aneurysm; IVC, inferior vena cava.

Table 2 Inferior vena cava (IVC) measurement and right atrial pressure[7 16]

Expiratory (max) diameter IVC	Collapse index (%) 100×(max − min diameter)/ max diameter	Estimated right atrial pressure
<2 cm	>40–50%	<10 mm Hg
>2 cm	<40–50%	>10 mm Hg

All of these signs, however, must be placed in the context of the patient's clinical state; such changes may be chronic in the context of cor pulmonale or previous pulmonary embolism. Adjuncts to the ACES protocol such as compressibility of the femoral veins for deep vein thrombosis (DVT) may be indicated in this situation to attempt to rule in an acute thrombus. However, the absence of thrombus in the leg veins does not exclude a pulmonary embolism.

Cardiogenic

Here the ACES protocol aims to identify gross abnormalities of cardiac function and size. The subjective visual assessment of global systolic function correlates with more formal quantitative measurements of left ventricular ejection fraction,[9] and emergency physicians with limited training show high inter-observer agreement with cardiology specialists.[10 11] A hypodynamic left ventricle in a hypotensive patient generally suggests a cardiogenic cause. Pleural effusions associated with cardiac failure may be seen on the right or left upper quadrant views.

Distributive

In this setting the ACES protocol can identify a hyperdynamic left ventricle, which has a 94% specificity for sepsis when applied to patients in the emergency department with non-traumatic undifferentiated hypotension.[12] Although the presence of a hyperdynamic heart carries a high positive prediction, in severe or late sepsis the myocardium may be depressed.

Adjuncts

Although these six views are the core components of the ACES protocol, it is recognised that, in certain clinical conditions, additional views may be advantageous. These adjuncts might include views of the femoral vein looking for the presence of DVT by the absence of compression of the vein. Other additional views may include parasternal and apical views of the heart, as well as thoracic views for pneumothorax.

Training

Basic training in focused emergency ultrasound (level 1 in the UK) includes competencies in FAST, aortic scanning and focused scanning for pleural and pericardial fluid.[13] Additional training and competencies will be required for a more detailed cardiac assessment and for assessment of the IVC. The level of training required to reliably perform an ACES protocol will need to be assessed in future studies, but current evidence suggests that the individual components of this protocol can be performed by emergency physicians with limited training.[11 14 15]

CONCLUSION

The ACES protocol consists of a cardiac view, an IVC view with collapse index, a view of the abdominal aorta, views for pleural and peritoneal fluid in the right and left upper quadrants and a pelvic view. There is mounting evidence for the use of focused ultrasound at the bedside in critically ill or injured patients. Specifically, it would appear to be useful in guiding the initial management while further information is obtained (eg, dynamic heart with empty IVC warrants fluid/poor heart function with a reasonable IVC filling requires inotropes). The use of ultrasound-guided IVC assessment for fluid management in critically ill emergency patients has yet to be validated in controlled studies. It may also be of value in the rapid assessment of the peri-arrested patient when the information is even more time critical but the scan is more likely to prove positive. We propose the six-view ACES protocol as a useful adjunct to clinical examination in patients with undifferentiated hypotension in the emergency department. A prospective randomised trial or multicentre database/registry is needed to investigate the validity and impact of this protocol on the early diagnosis and management of hypotensive patients.

Competing interests: PRTA, RJK, DL and DJMcA organise and teach on emergency ultrasound UK level 1 and advanced ultrasound courses at Addenbrooke's Hospital and Ipswich Hospital. PRTA and DL co-direct the focused ultrasound websites EmergencyUltrasound.org.uk and GPultrasound.org.uk. CGR organises and teaches on emergency training ultrasound courses in Basingstoke. JC organises and teaches on NEMUS emergency ultrasound courses in the Northern Deanery.

Ethics approval: The local ethics committee (Cambridgeshire 2) has approved analysis and publication of the cases included in this paper. No identifiable patient information has been used and all images of scans have been anonymised. Cases are example but typical cases taken from our collective experience.

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