ICU
MANAGEMENT & PRACTICE
INTENSIVE CARE - EMERGENCY MEDICINE - ANAESTHESIOLOGY
VOLUME 18 - ISSUE 4 - WINTER 2018

**SPECIAL SUPPLEMENT**
Aspen Symposium during ESICM 2018

# Imaging



## PLUS





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# Whole-body ultrasound in the intensive care unit

## Bedside ultrasound of the whole body

Whole-body ultrasound can be used in the evaluation of many critical conditions including encephalopathy where brain and ocular ultrasound combined with transcranial Doppler can identify elevated intracranial pressure. Hypoxaemia is mostly related to pulmonary disease and lung ultrasound can rapidly identify the aetiology. Cardiac, lung and abdominal ultrasound will be useful to identify both the mechanism and aetiology of haemodynamic instability. Finally, in any oligo-anuric patient, renal ultrasound should be performed. The use of ultrasound is further supported by several prospective and randomised trials.

Bedside ultrasound, also known as point-of-care ultrasound (POCUS), has been considered the new fifth pillar of physical examination (Narula et al. 2018) and is poised to replace the stethoscope. Based on its Greek etymology, the term "stethoscope" composed of stetho (breast) and scope (look into) may better suit miniaturised handheld ultrasound devices rather the tool invented by Laënnec in 1819 for auscultation. However, portable ultrasound devices have the ability to look beyond the chest. Therefore, the term "bodyscope" or whole-body ultrasound (WHOBUS) would more appropriately describe the potential of bedside ultrasound (Karabinis et al. 2010). It does not imply that the whole body should be examined every time, but rather that ultrasound can be used to complement clinical evaluation where indicated. Applications of ultrasound in the intensive care unit (ICU) are numerous, enabling simultaneous assessment of multiple organs. Two-dimensional (2D) or three-dimensional (3D) ultrasound offers a window into the anatomy of the patient, while haemodynamic physiology can be assessed using Doppler. In this article we describe current impact of the integration of WHOBUS into clinical care including specific clinical conditions that are common in the ICU and how WHOBUS can be used to identify the mechanism.

### WHOBUS and the encephalopathic patient

Altered mental status in a critically ill patient requires consideration of a broad differential diagnosis, including various causes of intracranial hypertension, metabolic derangements and drug intoxication. The diagnostic approach requires careful history, physical examination, and complementary diagnostic investigations. Point-of-care neurologic ultrasound in the encephalopathic patient enables the critical care physician to rapidly detect life-threatening conditions including (but not restricted to) the presence of raised intracranial pressure (ICP) (Maissan et al. 2015; Lau and Arntfield 2017; Denault et al. 2018), midline shift from a space occupying lesion such as traumatic brain injury or stroke (Denault et al. 2018), and cerebral vasospasm following subarachnoid haemorrhage (Denault et al. 2018). Furthermore, it can be used to confirm brain death (Ducrocq et al. 1998).

Examples of situations where point-of-care ultrasound may be useful in detection of intracranial hypertension include when invasive ICP monitoring is contraindicated (such as coagulopathy), or when a patient is too unstable to be transported for diagnostic imaging. Bedside intracranial pressure measurement with ultrasound is performed by placing a high frequency linear probe on the orbit to identify the optic nerve sheath diameter (ONSD) (**Figure 1**). An ONSD > 5.0 mm predicts the presence of ICP > 20 mmHg with a sensitivity of 94% and specificity of 98% (Maissan et al. 2015), representing excellent diagnostic performance (area under the curve [AUC] of 0.99) (Maissan et al. 2015) (**Figure 1**). Serial ONSD measurements can be done to follow the progression of ICP. Intracranial

hypertension may also be detected with ultrasound by measurement of blood flow velocity of the middle cerebral artery with spectral Doppler, known as transcranial colour-coded sonography (TCCS) (Lau and Arntfield 2017) (**Figure 2**). The pulsatility index (PI) is a Doppler-derived measure of the resistance to blood flow and is calculated as the difference between the peak systolic flow velocity and end-diastolic flow velocity, divided by the mean velocity. An elevated PI correlates with increased ICP, regardless of the nature of the intracranial pathology (Bellner et al. 2004). Typically a PI > 2.3 (normal PI value < 1.2) correlates with an ICP > 22 mmHg (Lau and Arntfield 2017). Presence of a midline shift of the cerebrum, a condition associated with ipsilateral intracranial hypertension, can also be detected by two-dimensional transcranial ultrasound. A transtemporal view of the third ventricle (**Figure 3**), a midline structure, is obtained and the distance to the middle of the third ventricle from the ipsilateral and contralateral edges of the cranium are measured; a discrepancy between the measured distances indicates presence of a midline shift (Denault et al. 2018).

An important caveat is that transcranial ultrasound requires an experienced operator, and even then is very difficult or impossible in up to 10% of patients (Denault et al. 2018). Detailed description of this technique is beyond the scope of this article but is well described elsewhere (Lau and Arntfield 2017; Denault et al. 2018).

Finally, it is important to perform a systematic evaluation of the encephalopathic patient, as extra-cranial causes of altered mental status are numerous, such as cerebral congestion secondary to right heart dysfunction or volume overload (**Figure 4**), or cerebral hypoperfusion due to various causes of shock. WHOBUS can help identify the presence of these contributing pathologic states as we will describe in the following sections.

## WHOBUS in the hypoxaemic patient

The approach to the hypoxaemic critically ill patient can be greatly simplified and enhanced with the use of point-of-care ultrasound (Piette et al. 2013). Lung and pleural ultrasound, as an adjunct to the clinical exam, can readily identify important causes of hypoxia

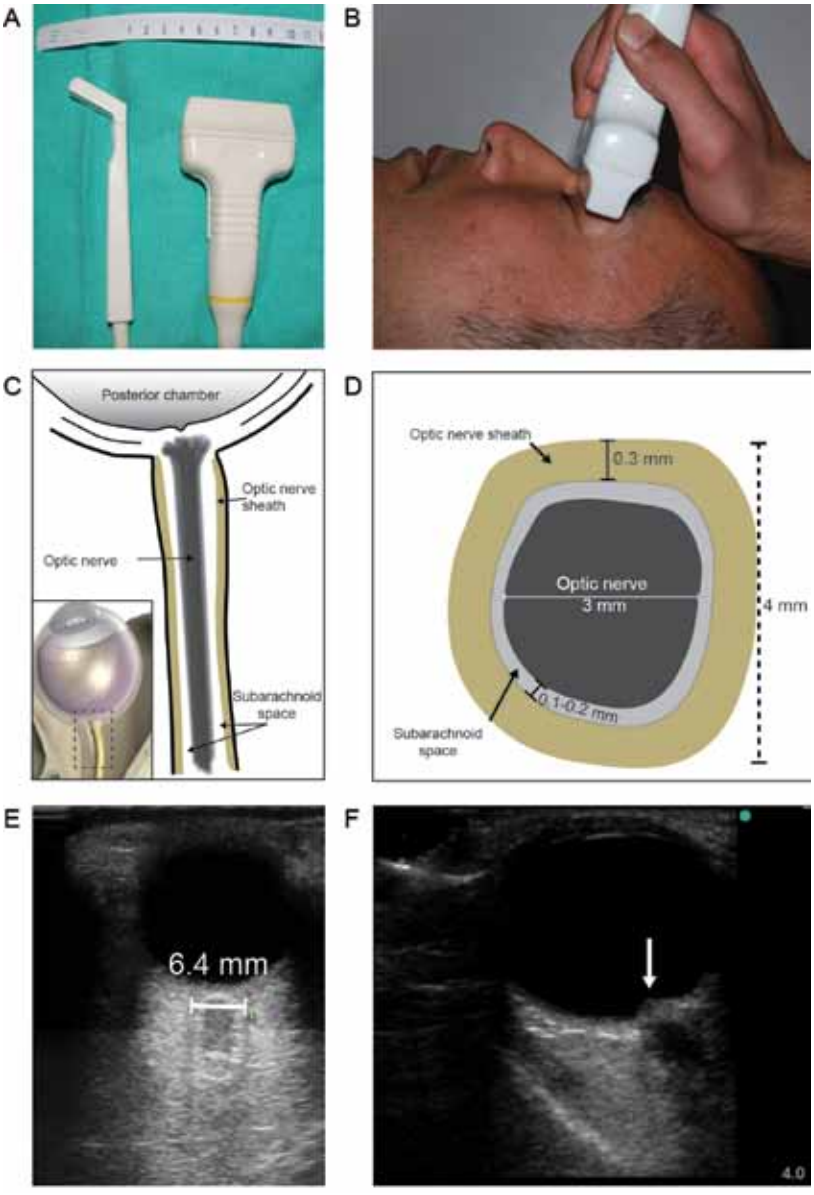


**Figure 1.** (A) Photo of high-frequency ultrasound (US) probes which can be (B) gently positioned over the eyelid of a closed eye. (C) Aspect of the eye and optic nerve sheath for which the measurement is taken at 3mm from the retina. (D) Cross sectional view of the optic nerve. (E) Dilated optic nerve and (F) papilloedema. (Adapted from Denault at al. 2018 and Soldatos et al. 2009).

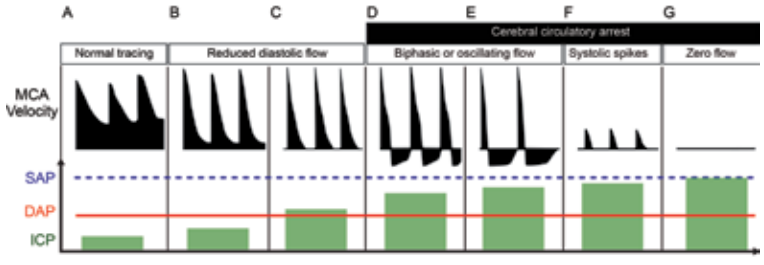


**Figure 2.** Intracranial hypertension and circulatory arrest. Transcranial Doppler changes in middle cerebral artery (MCA) mean flow with progressive increase in intracranial pressure (ICP) are shown compared with (A) normal MCA flow trace and normal ICP. (B,C) The initial stage has a normal pattern of systolic peaks with progressive (abnormal) reduction in diastolic velocities. (D-G)The three patterns that correspond to culmination in intracranial circulatory arrest are shown: biphasic oscillating flow, systolic spike flow and zero flow.

DAP diastolic arterial pressure SAP systolic arterial pressure

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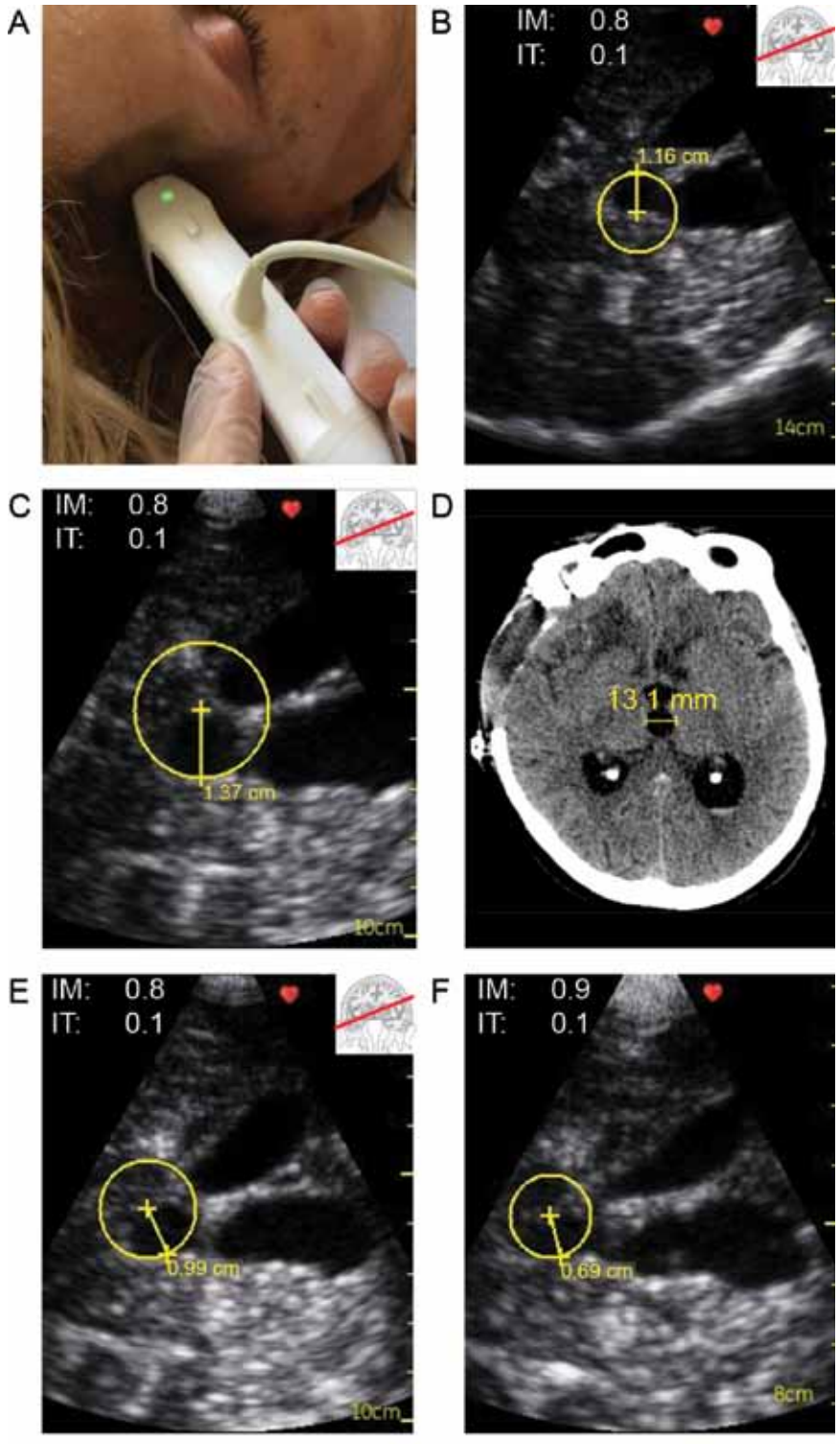


**Figure 3.** (A) Transcranial sonography (TCS) using a hand-held pocket ultrasound device (GE Vingmed Ultrasound AS, Horten, Norway) on a patient with craniectomy. (B) Prior to external ventricular drain (EVD) clamping, TCS showed a measurement of the 3rd ventricle at approximately 1.16cm. (C) On the third day, TCS showed a dilated 3rd ventricle measuring 1.37cm. (D) Computed tomography scan confirmed those sonographic findings showing a dilated 3rd ventricle measuring 1.31 cm (13.1mm). (E) One day after reopening the EVD, the size of the 3rd ventricle decreased to 0.99cm as measured by TCS. (F) The following day, it went down to 0.69 cm.

IM mechanical index IT thermal index
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and respiratory distress such as pulmonary oedema, acute respiratory distress syndrome, pneumothoraxes, pneumonia and pulmonary embolus.

The systematic, complete bilateral assessment of the chest allows the identification of key artefacts that are the result of the interplay between air, physiologic and pathologic tissue, pleura and fluid. When performed and interpreted correctly, the user can reach an accurate diagnosis, perhaps even obviating the need for other investigations such as chest radiography or computed tomography (Zanobetti et al. 2011; Volpicelli et al. 2008).

Numerous algorithms exist to direct users in the evaluation of the hypoxaemic patient (**Figure 5**), of which the BLUE protocol is probably the most well-known (Lichtenstein and Mezière 2008). The assessment begins with an examination of the anterior chest. The presence of lung sliding below the probe rules out a pneumothorax in that location. The absence of lung sliding does not enable a definitive diagnosis; however, a pneumothorax can still be ruled out by identifying a lung pulse in the pleura (fine oscillatory lung sliding from cardiac activity) or B lines, vertically projected pleural artefacts. Conclusive evidence of a pneumothorax can be identified by lung ultrasound by identification of a junction where areas of normal lung sliding and absent lung sliding meet the lung point (Zhang et al. 2006). Alveolar interstitial syndrome is identified if more than two B lines are seen in one intercostal space. Bilateral anterior B lines that have increased density in the dependent portions of the lung are characteristic of pulmonary oedema, where focal or skipped areas are more pathognomonic of pneumonitis or chronic interstitial disease respectively. A peripherally located focal lung consolidation could be a pulmonary embolus (Comert et al. 2013), which could be confirmed by detection of a deep venous thrombosis with ultrasound (Denault et al. 2018). Pleural effusion (**Figure 4**), consolidation and atelectasis (Lichtenstein et al. 2004) are usually found in the dependent lung regions. The volume of effusion can be estimated (Froudarakis 2008).

This modality is not without limitations, including the need for appropriate training, difficult imaging in obese patients or lung pathology that is very central with unaf-

fected pleural boundaries (Mayo et al. 2009; Denault et al. 2018). In such a situation, a transoesophageal approach can be considered (Cavayas et al. 2016). However, in conjunction with WHOBUS of other relevant organ systems as well as conventional clinical tools, the diagnostic yield remains high and will likely grow in conjunction with user expertise (Denault et al. 2018). Lung ultrasound has surpassed the popularity of transthoracic echocardiography in many centres (Yang et al. 2016). In 5 to 10% of the time, hypoxaemia will be associated with normal lung ultrasound. In those conditions, a cardiac aetiology such as intracardiac shunt (**Figure 6**), obstructive pulmonary diseases or acute pulmonary embolism should be suspected.

## WHOBUS in the haemodynamically unstable patient

A reported method of using WHOBUS to assist in management in haemodynamic instability involves a two-step approach (Vegas et al. 2014; Denault et al. 2014b). The first is to identify the mechanism of haemodynamic instability (distributive, haemorrhagic, cardiogenic or resistive), using a combination of inferior vena cava (IVC) and hepatic venous flow (HVF) interrogation (**Figure 7**). The second step is to identify the aetiology.

The initial step of identification of the mechanism of shock can be determined using the concept of venous return, which was popularised by Guyton et al. (1957). Haemorrhagic and distributive shock are typically associated with reduced systemic venous pressure. Cardiogenic shock is associated with an increase in right atrial pressure. Resistance to venous return can result from an infra-diaphragmatic obstruction such as abdominal compartment syndrome or a supra-diaphragmatic obstruction such as cardiac tamponade or tension pneumothorax. The IVC will be small in compartment syndrome (**Figure 8A-C**) and distended in tamponade. Rarely, IVC stenosis can occur after certain procedures such as liver transplantation (**Figure 8D**) and will be associated with a distended IVC with reduced ventricular cavities (Hulin et al. 2016). The hepatic venous flow will remain normal in shock states associated with preserved cardiac function (**Figure 7, pattern 1**) but will be abnormal when right ventricular dysfunction is present (**Figure 7 pattern 3**). However, in cases of resistance to venous return, absent or monophasic will be observed (**Figure 7 pattern 2&3**) (Beaubien-Souligny et al. 2018c).

A major advantage of WHOBUS over pres-

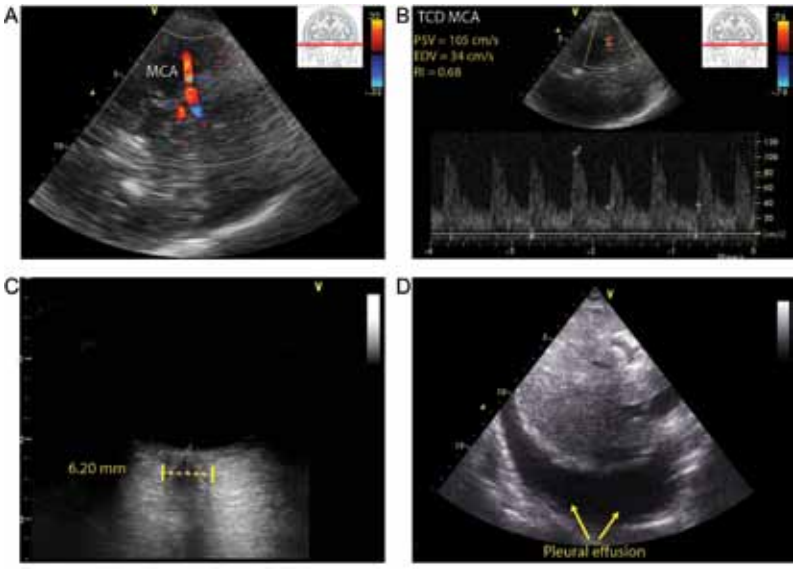


**Figure 4.** A 75-year-old man admitted to the intensive care unit for pneumonia and hypercapnic encephalopathy with right ventricular dysfunction from pulmonary hypertension. (A) Transcranial Doppler (TCD) of the right middle cerebral artery (MCA) showed a normal (B) resistance index (RI) of 0.68. (C) The optic nerve sheath diameter was 6.2mm and (D) using a left subcostal view, a pleural effusion was diagnosed. This imply that the dilated optic nerve sheath was not related to acute increase in intracranial hypertension but possibly secondary to an edematous state associated with right ventricular dysfunction.

EDV end-diastolic velocity PSV peak systolic velocity RI resistance index
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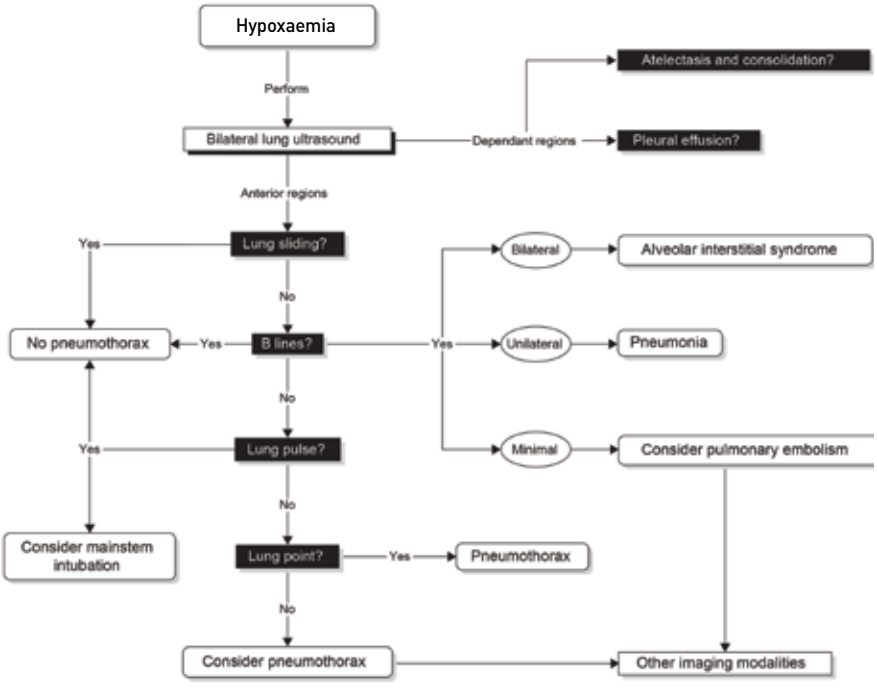


**Figure 5.** Lung ultrasound algorithm. Simple algorithm incorporating the notions presented in this chapter to assess the lung with ultrasound

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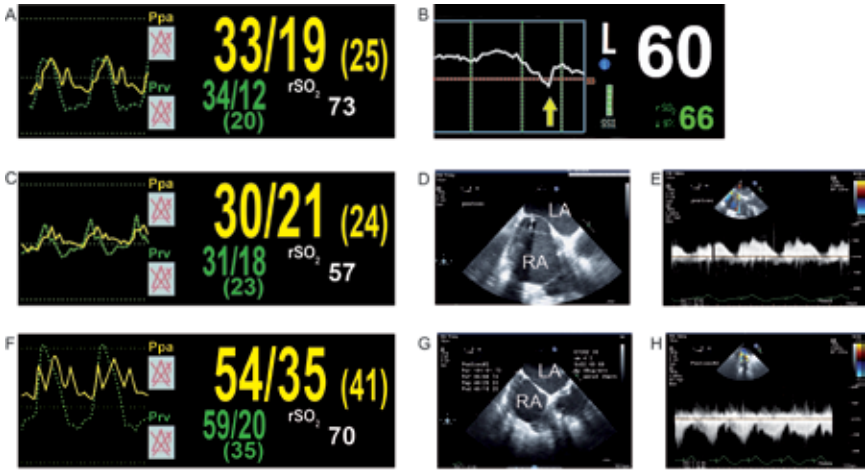


**Figure 6.** Acute right ventricular failure in a 70-year-old man undergoing aortic valve replacement. (A) His baseline pulmonary artery pressure (Ppa) and right ventricular pressure (Prv) waveform are shown. (B) Following separation from cardiopulmonary bypass (CPB) significant brain desaturation occurred (arrow on B) associated with haemodynamic instability. (C) The aspect of the Prv changed with diastolic pressure equalisation with the Ppa. (D) This was associated with right ventricular dysfunction and an atrial septal shift from the right atrium (RA) to the left atrium (LA). (E) This led to a right-to-left shunt across an atrial septal defect (ASD) with consequent hypoxaemia. (F) The patient returned on CPB and upon the second weaning attempt with the use of inhaled agents, adrenaline and increase in heart rate, the Prv increased and the diastolic pressure equalisation disappeared. (G) At the same time, the interatrial septum returned to a normal position and (H) the ASD shunt became left-to-right. This was associated with an increase in brain saturation ($rSO_2$) (B). The patient was extubated 2 hours later in the intensive care unit and had an uneventful post-op course.

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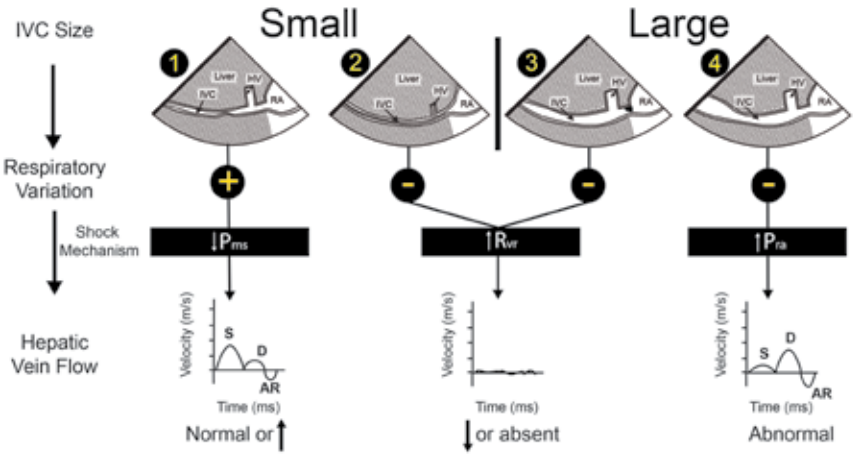


Projet 124 Figure 07

**Figure 7.** Shock mechanism. Algorithm to determine shock mechanism by using inferior vena cava (IVC) size, respiratory variation during spontaneous ventilation and hepatic venous flow (HVF) is shown. In patients with reduced mean systemic venous pressure (Pms) the IVC is small with respiratory variation (1) and the HVF is typically normal or increased due to the reduced dimension of the hepatic vein (HV). In patients with increased resistance to venous return (Rvr), the IVC can be collapsed from an abdominal compartment syndrome (2) or distended from a mechanical obstruction in the right atrial to IVC junction (3). In both situations, the HVF signal is significantly reduced, monophasic or absent. In a situation where the right atrial pressure (Pra) is increased, the IVC is dilated without respiratory variation (4) and the HFV will be abnormal with reduced systolic to diastolic velocity ratio.

AR atrial reversal velocity of the HVF D diastolic HVF velocity HV, hepatic vein IVC inferior vena cava Pms, mean systemic venous pressure RA, right atrium S systolic HVF velocity

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sure and flow-based monitors is the ability of WHOBUS to be used to identify the aetiology of shock. Reduced venous systemic pressure from blood loss into the pleural and peritoneal spaces is readily detected with WHOBUS, but gastrointestinal bleeding and retroperitoneal bleeding are more difficult to detect. Septic shock will reduce venous systemic venous pressure through an increase in venous compliance. Many infective causes are detectable with WHOBUS, such as pneumonia, empyema, cholecystitis, pyelonephritis, bacterial peritonitis in cirrhosis and endocarditis. Echocardiography is the gold standard for diagnosis of the aetiology of cardiogenic shock.

An important caveat is that two or more co-existing causes of haemodynamic instability may be present (Costachescu et al. 2002). In subarachnoid haemorrhage, myocardial depression can occur but also left ventricular outflow tract obstruction from the use of milrinone **(Figure 9)**. In septic shock both left and right-sided myocardial depression can be present (Kimchi et al. 1984; Romero-Bermejo et al. 2011; Turner et al. 2011; Vallabhajosyula et al. 2017), which if missed, may result in excessive fluid overload (Andrews et al. 2017). As mentioned, pulmonary oedema is readily detected with WHOBUS (Beaubien-Souligny et al. 2017). Portal pulsatility (**Figure 10**) predicts both portal hypertension and complications after cardiac surgery (Eljaiek et al. 2018 In press), including renal failure (Beaubien-Souligny et al. 2018a).

## WHOBUS in the oligo-anuric patient

The approach to the critically ill patient with an acute reduction of urine output involves multiple aspects. These include the rapid recognition of reversible causes and the accurate identification of patients who will progress to severe acute kidney injury (AKI). A blind approach consisting of administration of fluids in an attempt to increase urine output is often ill-advised as renal fluid responsiveness is absent in 50% of oliguric critically ill patients and resulting fluid overload may lead to complications (Prowle et al. 2010). Urinary sodium measurements are ineffective in identifying responders (Legrand et al. 2016).

WHOBUS may be used as an adjunct to enhance the evaluation of the oligoanuric patient. A proposed approach is presented in **Figure 11**. WHOBUS can not only be used to identify both presence and level of renal obstruction and urine formation, fluid responsiveness but can also be used to determine renal hypoperfusion and extra-renal haemodynamic factors contributing to renal hypoperfusion. These concepts are beyond the scope of this short article.

Kidney and bladder ultrasound are enabling clinicians to rapidly screen for the possibility

of lower or higher urinary tract obstruction. Lower urinary tract obstruction can occur frequently in critically ill patients because of urinary catheter dysfunction. Hydronephrosis may occur in the setting of urologic or other types of abdominal surgery (Narita et al. 2017) as well as retroperitoneal bleeding (Yumoto et al. 2018). After excluding urinary obstruction, Doppler ultrasound can be used to assess intra-renal blood flow velocities. Colour Doppler showing no signals in the renal parenchyma after adequate scale adjustments may offer a simple way to identify kidney hypoperfusion (Schnell and Darmon 2012; Barozzi et al. 2007; Schnell et al. 2014). The use of pulse-wave Doppler may have two applications. Arterial Doppler of the interlobar artery can identify patients with a highly abnormal resistive index (RI > 0.70). While this parameter is modified by numerous factors, a high RI has been demonstrated to be predictive of subsequent AKI or progression to severe AKI in critically ill patients and thus may be useful to identify which oliguric patients are the most concerning (Ninet et al. 2015). Venous Doppler at the level of the interlobar veins can assess whether alterations in intra-renal venous flow (periods of interrupted flow) are present (Iida et al. 2016; Nijst et al. 2017). The presence of severe alterations (venous flow present only in diastole) may suggest that venous hypertension is present and have a deleterious effect on kidney function, as it has been associated with AKI after cardiac surgery (Beaubien-Souligny et al. 2018b; 2018a).

## The impact of WHOBUS

In order to explore the impact of WHOBUS, we performed a search based on a systematic review reported by Heiberg et al. (2016) with the aim of identifying the impact on diagnosis, management and outcome of POCUS in the emergency room, intensive care unit and the operating room. PubMed, MEDLINE and EMBASE electronic databases were searched using the following search terms: ("Echocardiography" OR "Ultrasonography") OR "Heart Diseases/Ultrasonography" AND ("Perioperative Care" OR "Intensive Care" OR "Emergency Department") AND ("Humans"). The references of each publication were searched for eligible publications. The search was restricted to peer-reviewed, original research, including prospective, retrospective cohort, case–control and cross-sectional studies, but excluded systematic reviews, case reports, non-English language publications, studies published before 1 January 1995 or publications without the full text being available. Participants were

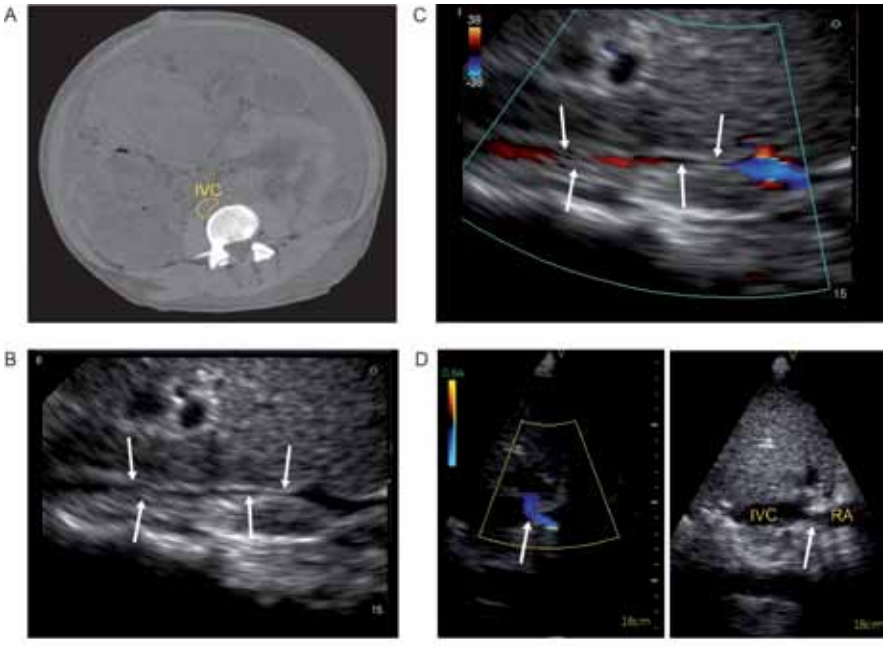


**Figure 8.** (A) Computed tomography of a patient with abdominal compartment syndrome. (B) Zoomed subxiphoid longitudinal view of the inferior vena cava (IVC) using bedside ultrasound shows a reduced diameter of the IVC (arrows). (C) In some patients, the compressed IVC can only be identified using colour Doppler (arrows). (D) Longitudinal subxiphoid view by ultrasound of a mechanical stenosis of the IVC (arrow) in a haemodynamically unstable patient after liver transplantation. Note the colour flow acceleration (arrow) at the level of the IVC stenosis.

RA right atrium

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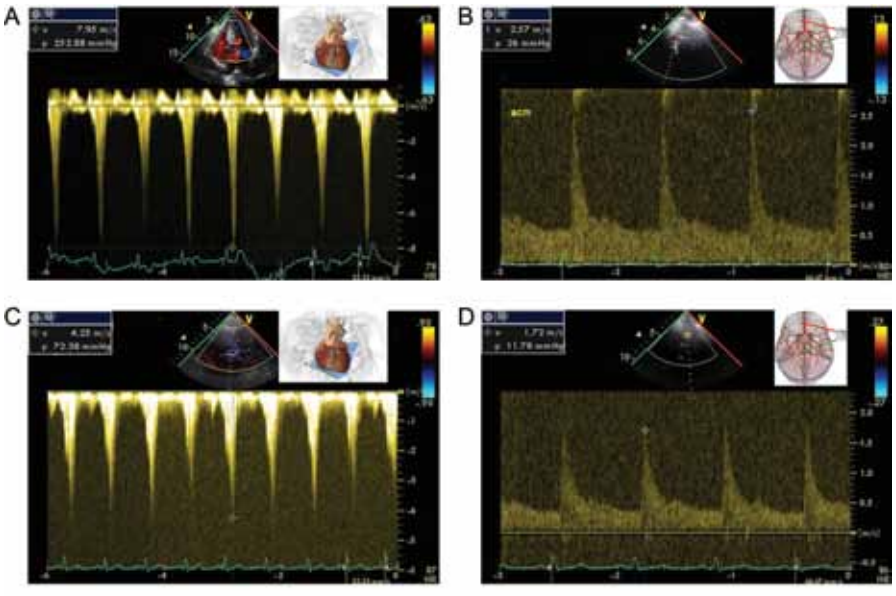


**Figure 9.** Left ventricular outflow tract (LVOT) obstruction. A 31-year-old man with subarachnoid haemorrhage receiving intravenous milrinone develops LVOT obstruction. (A) Note the significant pressure gradient (252 mmHg) and velocities (7.9 m/s) across the LVOT obtained using an apical five-chamber view. (B) The associated transcranial Doppler velocities of the right middle cerebral artery (MCA) were 2.57 m/s. (C,D) Following a bolus of 500mL of crystalloid, (C) the LVOT gradient drops to 72 mmHg and (D) the right MCA velocity decreases to 1.72 m/s.

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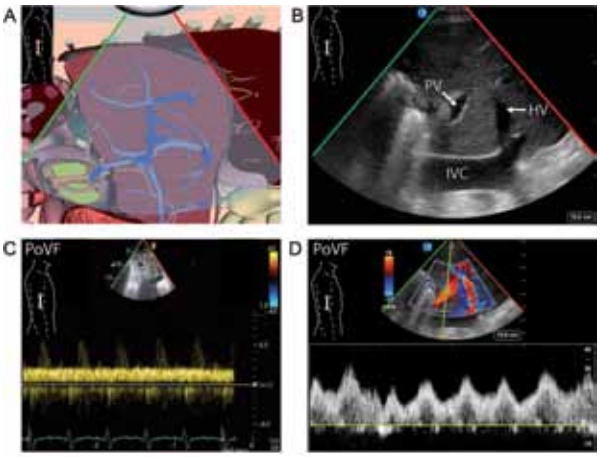


**Figure 10.** Portal venous flow. (A) Portal venous flow (PoVF) assessment from a posterior axillary line coronal view. (B) Using the same view, the inferior vena cava (IVC), portal vein (PV) and hepatic vein (HV) can be seen. Note the increased echogenicity of the PV wall. (C) Normal portal vein pulsed-wave Doppler has a monophasic signal indicating that blood is directed toward the transducer. Note the background pulsatile higher velocity of the hepatic artery, which is in the same direction. (D) Abnormal pulsatile portal flow with a pulsatility fraction of more than 50%. This finding indicates portal hypertension which, in right heart dysfunction, is associated with increased risk of complications.

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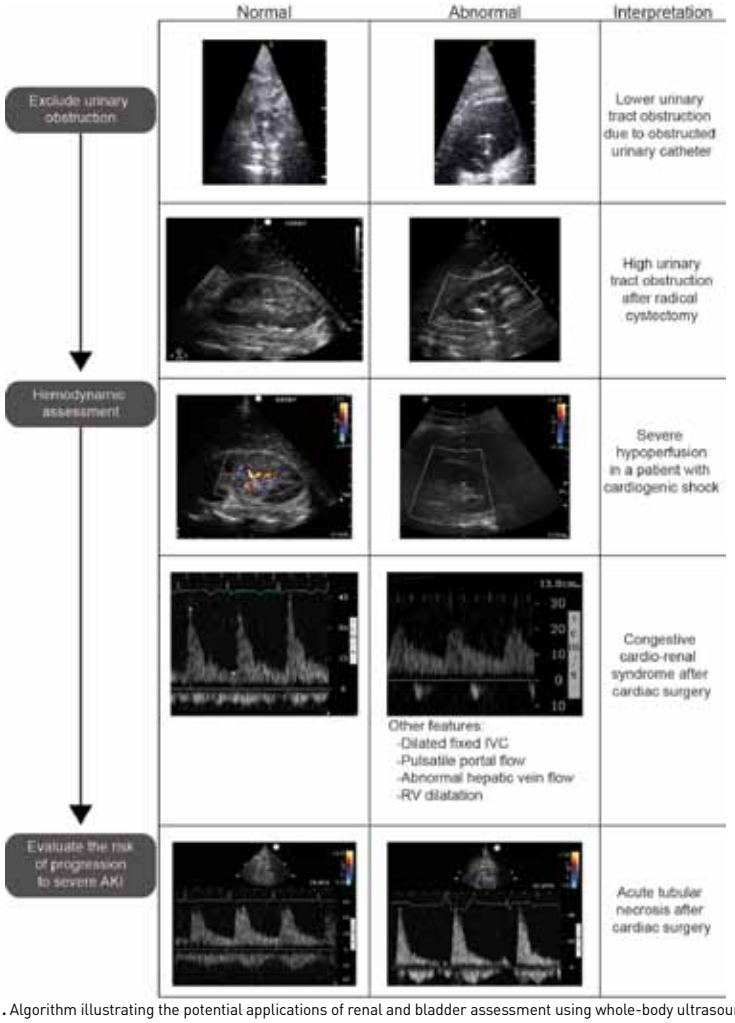


**Figure 11.** Algorithm illustrating the potential applications of renal and bladder assessment using whole-body ultrasound at the bedside of critically ill patients.

AKI acute kidney injury IVC, inferior vena cava RV right ventricle

humans aged at least 18 years. The intervention was focused echocardiography, lung ultrasound, abdominal ultrasound or deep venous thrombosis ultrasound performed either before, during or after non-cardiac surgery or in a critical care or emergency medicine setting. Outcomes included changes in clinical diagnosis, management, cardiac complications and death. For each individual publication, an outcome-level assessment of bias was performed that included the following parameters: patient selection, sonographer expertise, indication for surgery and indication for ultrasound. This bias assessment was considered in the synthesis of the result, but no scoring system was used. The impact on diagnosis, management and outcome of ultrasound of 2,020 patients are summarised in **Table 1**. Most studies were observational studies with few, randomised controlled trials. Changes in management and diagnosis range from 8% to 78%. Many of these studies have limited the use of ultrasound to the chest or the abdomen. There is a paucity of studies investigating whether an approach guided by ultrasound improves clinical outcomes. Consequently, there is an unmet need to design pragmatic trials to address these questions.

## Conclusion

The clinical uses of ultrasound in critical care are increasing. Whole-body ultrasound is becoming a routine and useful tool for the critical care physician and is becoming incorporated into critical care training (Diaz-Gomez et al. 2017). ■

### Conflict of interest

André Denault is on Speakers Bureau for CAE Healthcare and Masimo.

### Abbreviations

AKI acute kidney injury
HVF hepatic venous flow
ICP intracranial pressure
ICU intensive care unit
IVC inferior vena cava
ONSD optic nerve sheath diameter
PI pulsatility index
POCUS point-of-care ultrasound
TCCS transcranial colour-coded sonography
WHOBUS whole-body ultrasound

## References

**For full references, please email editorial@icu-management.org or visit https://iii.hm/qp2**

**Table 1.** Impact of point-of-care focus cardiac ultrasound (FCU) on diagnosis, management and outcome of patients in the anaesthesia and intensive care setting

| First author, year | Methodology | Ultrasound operator | Cohort | Summary |
|---|---|---|---|---|
| **Impact of FCU on diagnosis and management** | | | | |
| **Emergency department and pre-hospital setting** | | | | |
| Breitkreutz 2010 | Randomised controlled trial | Emergency physicians | 204 patients undergoing cardiopulmonary resuscitation (100) or in shock (104) | In 35% of those with an electrocardiographic (ECG) diagnosis of asystole, and 58% of those with pulseless electrical activity, coordinated cardiac motion was detected, and associated with increased survival. Echocardiographic findings altered management in 78% of cases. |
| Chardoli 2012 | Randomised controlled trial | Emergency physician residents | 100 patients with out-of-hospital cardiac arrest requiring cardiopulmonary resuscitation with initial diagnosis of pulseless electrical activity. 50 randomised to FCU and 50 controls | FCU identified mechanical ventricular activity in 78% (i.e. not pulseless electrical activity but shock) in whom FCU identified pericardial effusion in 14% and hypovolaemia in 22%. Return of spontaneous circulation occurred in 43% of patients where mechanical ventricular activity was identified with FCU. No patients had return of spontaneous circulation where FCU identified no mechanical ventricular activity.<br>Among patients who did not receive FCU, no reversible aetiology was detected. However, there was no significant difference in resuscitation results between groups (p =0.52). |
| Levitt 2002 | Prospective non-comparative observational study | Cardiac sonographers | 83 patients admitted with either chest pain (45) or dyspnea (38) with clinical suspicion of cardiovascular pathology by a senior emergency physician | There was a change in diagnosis in 45%, a change in management in 30%, and a change in disposition in 13% of patients. |
| Jones 2004 | Randomised controlled trial | Attending emergency physicians | 184 patients with nontraumatic hypotension and symptoms of shock (e.g. syncope, dyspnea, unresponsiveness, fatigue) of whom 88 received FCU on admission and 96 received FCU 15-30 minutes after admission | Early FCU increased the likelihood of detecting the correct diagnosis of hypotension from 50% to 80%. |
| **Anaesthesia setting** | | | | |
| Canty 2009 | Prospective non-comparative observational | Anaesthesiologists | 87 patients undergoing non-cardiac surgery (preoperative, intraoperative and postoperative) received FCU when transthoracic echocardiography (TTE) was requested by the attending aneasthesiologist | FCU changed medical management in 34% (haemodynamic management, anaesthetic technique, and postoperative care) and surgical management in 7% (surgery altered in 2% and deferred in 5%). |
| Cowie 2011 | Prospective non-comparative observational | Anaesthesiologists | 170 patients scheduled for elective or non-elective surgery with either haemodynamic instability, undifferentiated murmur / valve disease, suspected ventricular dysfunction, dyspnea or hypoxaemia, poor functional capacity, suspected pulmonary hypertension or dysrhythmia | FCU changed management in 82% of patients (same changes as above). |
| Canty 2012a | Prospective non-comparative observational | Anaesthesiologists | 100 patients scheduled for elective non-cardiac, non-minor surgery who were referred for preoperative assessment by an anaesthesiologist in the preoperative clinic where the anaesthesiologist suspected significant cardiac disease or patient age>65 years | FCU changed management in 54% including changed surgery in 2%. Changes included a step up in treatment in 36% (delay surgery for cardiology assessment, intraoperative invasive monitoring and vasopressor infusion, postoperative intensive care unit (ICU)) and a step down in treatment in 8% (circumvented the need for invasive monitoring, vasopressor infusion, postoperative ICU admission). |
| Canty 2012c | Prospective non-comparative observational | Anaesthesiologists | 99 patients scheduled for urgent (non-elective surgery) where the attending anaesthesiologist suspected significant cardiac disease or patient age>65 years | FCU changed diagnosis in 67% and changed management in 44% including changed surgery in 2%. Changes included a step up in treatment in 20% and a step down in treatment in 34% (same changes as above). |
| Botker 2014 | Prospective non-comparative observational | Anaesthesiologist | 112 patients scheduled for urgent (non-elective) non-cardiac surgery were screened with FCU before surgery | FCU changed the diagnosis in 17% and changed management in 12%. |
| **Intensive care setting – screening** | | | | |
| Manasia 2005 | Prospective non-comparative observational | Intensivists who received brief training and FCU checked by cardiac sonographers | 90 patients admitted to intensive care after non-cardiac surgery and cardiac surgery | FCU changed diagnosis in 84% and changed management in 37%. FCU imaging was diagnostic in 94% and interpreted correctly in 84%. |
| Stanko 2005 | Prospective non-comparative observational | Cardiac sonographers | 90 patients admitted to intensive care after non-cardiac surgery and cardiac surgery | FCU led to changed management in 41% of patients. Major changes occurred in 8% (surgery changes or other new active treatment) and minor changes in 92% (medication changes or referral). |
| Marcelino 2008 | Prospective non-comparative observational | Intensivists | 704 patients admitted to intensive care received FCU | FCU revealed abnormal findings in 33%, of which 7.5% were severe. |
| Christiansen 2013 | Prospective non-comparative observational | Intensivists | 80 patients received FCU and lung ultrasound 1 day after open aortic valve replacement | FCU and lung ultrasound changed the diagnosis of pericardial and pleural effusion in 51% of patients. |
| **Intensive care setting – FCU indicated** | | | | |
| Joseph 2004 | Prospective non-comparative observational | Cardiac sonographers | 100 patients admitted to intensive care with shock (systolic blood pressure < 100mmHg or fall in systolic blood pressure of ≥25% and inotrope use or evidence of low output or pulmonary/venous congestion) received FCU | Cardiac cause of shock was identified by FCU in 63%. FCU resulted in a change in management in 51%, including 29% medical therapy changes and 22% procedural changes (surgery 12%, pericardiocentesis 4%, intra-aortic balloon pump 4%, thrombolysis 2%, angioplasty 1%). |
| Orme 2009 | Prospective non-comparative observational | Intensivists | 187 patients admitted to intensive care after non-cardiac surgery. Indications included LV and RV assessment, infective endocarditis, pericardial effusion, and pulmonary oedema. | FCU led to a change in management in 51% of patients and included changes to fluid administration, inotrope or drug therapy, and treatment limitation. The main impact was in haemodynamically unstable patients. Diagnostic images were obtained in 91.3% of spontaneously breathing and 84.2% of mechanically ventilated patients. |
| **Impact of FCU on outcome** | | | | |
| Plummer 1992 | Retrospective comparative cohort study | Emergency physicians | 49 patients admitted to the Emergency Department with penetrating cardiac injury of whom 28 received FCU on arrival and 21 did not | In patients who received FCU there was greater survival (100% vs 57.1%, p=0.01), Glasgow Outcome Score (5.0 vs 4.2, p=0.007) and a shorter time to diagnosis and disposition for surgical intervention (15.5±11.4 vs 42.4±21.7 minutes p < 0.001). |

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| Canty 2012b | Retrospective comparative cohort study | Anaesthesiologists | 130 patients scheduled for hip fracture surgery at two institutions of whom 64 received preoperative FCU and 66 matched controls who did not receive FCU | Preoperative FCU was associated with lower mortality at 30 days (4.7% vs 15.2%, p=0.047, number needed to treat 9.5) and 12 months after surgery (17.1% v 33.3%, p=0.031, number needed to treat 6.2). |
| Ferrada 2014 | Randomised controlled trial | Surgeons, Emergency Department physicians, emergency medicine and surgical residents | 215 patients admitted to the Emergency Department with blunt or penetrating trauma with systolic blood pressure <100mmHg, mean arterial blood pressure <60mmHg or heart rate >120 beats per minute | Patients who received FCU received less fluids (1.5L vs 2.5L, p < 0.0001), less time to surgery (35.6 minutes vs 79.1 minutes, p=0.0006), higher rate of intensive care unit admission (80.4% vs 67.2%, p=0.04) and mortality was lower but not statistically significant (11.0% vs 19.5%, p=0.09). |
| Kanji 2014 | Retrospective comparative cohort study | Intensivists | 110 patients admitted to intensive care with shock (despite vasopressor infusion and intravenous fluid challenge achieving a central venous pressure (CVP) of at least 8mmHg) received FCU compared with 110 matched retrospective controls who did not receive FCU | Patients receiving FCU received less fluids (49 (33-74) vs 66 (42-100) mL/kg, p=0.01), more dobutamine infusions (22% vs 12%, p=0.01). FCU was associated with less mortality at 28-days (34% vs 44%, p=0.04, NNT 9.1), less stage 3 acute kidney injury (20% vs 39%), and more days alive and free of renal support (28 (9.7-28) vs 25 (5-28), p=0.04). |
| Canty 2018 | Pilot randomised controlled trial | Anaesthesiologists | 100 patients scheduled for hip fracture surgery of whom 49 received 49 preoperative FCU and 51 controls who did not receive FCU | FCU altered the management of 35% of participants. The 30-day primary composite outcome of any death, acute kidney injury, non-fatal myocardial infarction, stroke, pulmonary embolism or cardiac arrest within 30 days of surgery occurred in 7 of the FCU group patients and 12 of the control group patients (group separation 39.3%). Number needed to treat (NNT) 10.9. |
| **Impact of lung ultrasound or/and FCU on diagnosis and management** | | | | |
| **Ultrasound screening** | | | | |
| Christiansen 2013 | Prospective non-comparative observational | Intensivists | 80 patients received FCU and lung ultrasound 1 day after open aortic valve replacement | FCU and lung ultrasound (LUS) changed the diagnosis of pericardial and pleural effusion in 51% of patients. |
| Alsaddique 2016 | Prospective non-comparative observational | Cardiac sonographers | 91 patients received FCU and lung ultrasound 1 day after cardiac surgery requiring median sternotomy | FCU and/or LUS changed the diagnosis of important cardiac and/or respiratory disorders in 67% including cardiac dysfunction (42%), pericardial effusion (5%), mitral regurgitation (2%), hypovolaemia (1%), pleural effusion (33%), pneumothorax (4%), alveolar interstitial syndrome (3%) and pneumonia (1%). |
| Ford 2017 | Prospective non-comparative observational study | Medical students with images reviewed by a surgeon | 78 patients undergoing cardiac or thoracic surgery received lung ultrasound and chest radiography either before (42 patients) or after (36 patients) surgery (not in intensive care) | LUS identified lung pathology that was missed by clinical assessment and chest x-ray in 20% of patients. Lung ultrasound detected lung pathology in 10 of 42 (24%) patients before surgery in the preoperative clinic and in 34 of 36 (94%) patients after surgery. |
| Haji 2018 | Prospective non-comparative observational | Intensivists | 93 patients admitted within <24h to intensive care received FCU and lung ultrasound | Haemodynamic diagnosis was altered in 66% of participants, including new (14%) or altered (25%) abnormal haemodynamic states or exclusion of clinically diagnosed abnormal haemodynamic state (27%). Valve pathology of at least moderate severity was diagnosed for mitral regurgitation (7%), aortic stenosis (1%), aortic stenosis and mitral regurgitation (1%), tricuspid regurgitation (3%), and 1 case of mitral regurgitation was excluded. Management changed in 65% of participants including increased (12%) or decreased (23%) fluid therapy, and initiation (10%), changing (6%) or cessation (9%) of inotropic, vasoactive or diuretic drugs. |
| **Ultrasound indicated** | | | | |
| Silva 2013 | Prospective non-comparative observational study | Intensivists | 78 patients admitted to intensive care with acute respiratory failure received FCU, lung and deep venous thrombosis (DVT) ultrasound | Ultrasound was more accurate than standard assessment (83% vs 63%, p=0.02) resulting in a change in diagnosis of 20%. Receiver operating characteristic curve (ROC) analysis showed greater diagnostic performance of ultrasound than standard approach in pneumonia (0.74+-0.12 vs 0.87+-0.14, p=0.02), acute haemodynamic pulmonary oedema (0.79+-0.11 vs 0.93+-0.08, p=0.007), decompensated chronic obstructive pulmonary disease (0.8+-0.09 vs 0.92 +- 0.15, p=0.05), and pulmonary embolism (0.81 +- 0.17 vs 0.65+-0.12, p=0.04). |
| Bataille 2014 | Prospective non-comparative observational study | Intensivists | 136 patients admitted to intensive care with acute respiratory failure received FCU and lung ultrasound | The diagnostic accuracy of combined FCU and lung ultrasound was greater than lung ultrasound alone (p=0.05). Comparisons between ROC curves showed that combined FCU and lung ultrasound improves the diagnosis of acute haemodynamic pulmonary oedema (p=0.001), pneumonia (p=0.001), and pulmonary embolism (p=0.001). |
| Xirouchaki 2014 | Prospective non-comparative observational study | Intensivists | 253 patients admitted to the intensive care unit (108 in patients with unexplained hypoxaemia and 145 with suspected lung pathology) received lung ultrasound | LUS changed the diagnosis in 86% and changed the management in 47%, consisting of invasive interventions (chest tube, bronchoscopy, diagnostic thoracentesis/fluid drainage, continuous venous–venous haemofiltration, abdominal decompression and tracheotomy) in 32% and noninvasive interventions (positive end-expiratory or PEEP change/titration, recruitment manoeuvre, diuretics, physiotherapy, change in bed position, antibiotics initiation/change) in 15%. |
| Zanobetti 2017 | Prospective non-comparative observational study | Emergency physicians | 2,683 patients admitted to the Emergency Department with dyspnea received FCU and lung ultrasound | Average time to diagnosis was lower in patients who received ultrasound compared to those who received standard evaluation without ultrasound (24+-10 min vs 186+-72 min, p=0.025). The diagnostic accuracy was similar for acute coronary syndrome, pneumonia, pleural effusion, pericardial effusion, pneumothorax, and dyspnea from other causes. Ultrasound was more accurate in diagnosis of heart failure and standard evaluation was more accurate in the diagnosis of chronic obstructive pulmonary disease/asthma and pulmonary embolism. |
| **Impact of lung ultrasound or/and FCU on outcome** | | | | |
| Laursen 2014 | Randomised controlled trial | Respiratory physician | 317 patients admitted to the Emergency Department with respiratory rate of more than 20 breaths per minute, oxygen saturation of less than 95%, requiring oxygen therapy, dyspnea, FCU, lung and DVT ultrasound, cough, or chest pain. 158 received ultrasound on admission and 157 did not. | Patients receiving ultrasound had a higher proportion of correct presumptive diagnosis at 4 hours after admission (88.0% [82.8–93.1] vs 63.7% [56.1–71.3], p<0·0001). No differences were found in hospital length of stay or in-hospital mortality. |
| Atkinson 2018 | Randomised controlled trial | Emergency physicians | 270 selected patients admitted to the Emergency Department with persistent hypotension in whom 136 received point-of-care ultrasound (FCU, lung and abdomen) and 134 controls who did not receive point-of-care ultrasound | Follow-up was completed for 270 of 273 patients. The most common diagnosis in more than half the patients was occult sepsis. There was no difference between groups for the primary outcome of 30-day survival (point-of-care ultrasonography group 104 of 136 patients versus standard care 102 of 134 patients; difference 0.35%; 95% binomial confidence interval [CI] −10.2% to 11.0%), survival in North America (point-of-care ultrasonography group 76 of 89 patients versus standard care 72 of 88 patients; difference 3.6%; CI −8.1% to 15.3%), and survival in South Africa (point-of-care ultrasonography group 28 of 47 patients versus standard care 30 of 46 patients; difference 5.6%; CI−15.2% to 26.0%). There were no important differences in rates of computed tomography (CT) scanning, inotrope or intravenous fluid use, and ICU or total length of stay. |