15-minute consultation: Using point of care ultrasound to assess children with respiratory failure

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ABSTRACT
Point of care ultrasound (POCUS) is well established in adult emergency medicine and critical care. It is used for immediate diagnosis and evaluation of the impact of bedside interventions in the acutely unwell child. This article highlights how ultrasound can be helpful in paediatric practice when dealing with the neonate, infant or older child with undifferentiated respiratory distress, respiratory failure or ventilation problems. It highlights indications for use, key diagnostic features of common pathology and outlines the benefits of POCUS in everyday practice.

WHAT IS POINT OF CARE ULTRASOUND?
Point of care ultrasound (POCUS) is a focused ultrasound performed by the bedside clinician to answer predefined questions and provides an immediate answer, potentially guiding lifesaving therapies. Examples include: is there a pneumothorax? Is there a pleural effusion? Is there pulmonary oedema? And is the myocardial function reduced? POCUS is different to radiology-provided ultrasonography. It is not used to describe complex pathology or the morphological appearances of organs and is an augmentation, not replacement of radiology provision.

HOW DID POINT OF CARE ULTRASOUND DEVELOP?
POCUS has been well established in adult emergency medicine and critical care for several years. It is familiar to many clinicians to aid with procedures, such as intravenous access.
Indeed, there is recent randomised controlled trial evidence to show success rate, fewer attempts and reduced complication rates in internal jugular vein cannulation can be achieved when the procedure is ultrasound guided, compared with the anatomical landmark technique, but it offers much more than support for practical procedures.1 2

It was first applied as Focused Assessment by Sonography in Trauma (FAST) scanning in emergency departments. It aided both diagnosis and management of life-threatening injuries in patients without the need for transportation to a CT scanner. The aim of the FAST scan is to identify fluid in the pelvis and abdomen, which may require immediate intervention.

This has been ‘extended’ to the ‘eFAST’ scan, which includes assessment of the lungs for pneumothorax and/or haemothorax and pericardial effusions.3 4 Protocols now exist to assess the adult medical patient with common presentations, such as shock, chest pain and respiratory distress. Its use has also been extended to both the medical wards and intensive care unit.

The use of POCUS in paediatrics has thus far been limited, but is now a rapidly growing assessment tool. Understanding the use of POCUS can help you facilitate its use in a paediatric emergency situation and encourage you to develop the skills yourself.

HOW WOULD I USE POINT OF CARE ULTRASOUND IN PAEDIATRICS?
Consider POCUS as an extension of the bedside clinical assessment. It enables you to rapidly evaluate a list of differential diagnoses using a predefined set of questions often leading to simple binary decisions, for example, pneumothorax: present or not. POCUS also allows repeated scanning of the same patient to assess the impact of an intervention and improves patient safety during invasive procedures.5 7
Best practice

While POCUS is a sensitive and specific marker for many conditions (pneumothorax, pulmonary oedema, pleural effusion), POCUS should be used as any other test: a supplementary diagnostic tool. Table 1 compares the sensitivity and specificity of lung POCUS with the chest radiograph.

POCUS can be used to assess any body system, in any setting, and is particularly useful in the assessment of the newly presenting critically unwell neonate/child.1 5 8 9

We would encourage you to use your experienced adult teams during POCUS assessment of an acutely unwell child, as they will have completed formal adult accredited training, which is currently under development in paediatrics. Attendance at a formal ultrasound course is also strongly recommended, followed by a well-supported mentoring process.10 Work is now ongoing to create a UK paediatric-specific critical care ultrasound course, curriculum and mentoring systems.11

WHAT ARE THE PROS AND CONS OF POINT OF CARE ULTRASOUND?

Figure 1 illustrates some of the benefits and drawbacks to the use of POCUS.

LUNG POINT OF CARE ULTRASOUND

The probe selection and location

Optimal assessment requires the correct ultrasound probe. A linear probe in infants and a curved linear probe in older children are used. The probe is placed in a longitudinal position, with the probe marker conventionally used to represent the head of the patient.

Figure 2 gives a guide as to which POCUS probe is best used for which structure.3 4

Correct scanning requires the sequential assessment at various locations across both lungs, analogous to the structured approach used when listening to the chest with a stethoscope. Figure 3 demonstrates the key zones of the lung which must be scanned when performing a full lung POCUS. In an emergency

<table>
<thead>
<tr>
<th>Pathology diagnosis</th>
<th>Chest X-ray</th>
<th>Lung POCUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensitivity (%)</td>
<td>Specificity (%)</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>46</td>
<td>100</td>
</tr>
<tr>
<td>Pleural effusion</td>
<td>51</td>
<td>99</td>
</tr>
<tr>
<td>Consolidation</td>
<td>77–86</td>
<td>91–96</td>
</tr>
<tr>
<td>Pulmonary oedema</td>
<td>50–68</td>
<td>76–83</td>
</tr>
</tbody>
</table>

POCUS, point of care ultrasound.

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**Table 1** Sensitivity and specificity of lung POCUS compared with X-ray

**Figure 1** Benefits and drawbacks of using point of care ultrasound.

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No radiation
Immediate results
Minimal movement of patient
Safe and validated tool
Quick, instant feedback
Repeated scans in same patient easily
Relatively cheap
May reduce unnecessary interventions
Promotes time at the bedside of a critically ill child
Clear detailed pictures are relatively easy to obtain in the paediatric population

Accuracy altered by skill of practitioner
Patient habitus alters accuracy
Type of fluid difficult to distinguish (e.g. Blood vs. serous fluid)
Majority of evidence base is in adult population
Can be difficult to store images from a governance perspective
Challenging to get training as a paediatrician
Best practice

<table>
<thead>
<tr>
<th>Probe Description</th>
<th>Probe Appearance</th>
<th>Good For:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phased Array</td>
<td>Cardiac POCUS</td>
<td>Neonatal Head</td>
</tr>
<tr>
<td>Linear</td>
<td>Superficial Structures Vascular Lungs in infants/neonates</td>
<td></td>
</tr>
<tr>
<td>Curved-Linear</td>
<td>Deep structures Lungs in older humans Abdominal POCUS</td>
<td></td>
</tr>
</tbody>
</table>

**Box 1** Point of care ultrasound findings of normal lung

- **Bat-wing sign**: the ribs will provide ‘drop out’ of ultrasound signal either side of the lung parenchyma producing the ‘bat-wing’ sign (figures 4 and 5). In neonates with underdeveloped ribs, you may not see this sign as clearly, and may just see the ribs as circular structures.
- **Pleural line**: the dense white pleural line should be identified. With the probe held static you will see this dense white line ‘creeping’ forwards and backwards (representing normal pleural sliding). Failure to see pleural sliding often represents unventilated lung (eg, pneumothorax, endobronchial intubation) (figures 4 and 5).
- **Sea-shore sign**: motion (M)-mode is an ultrasound tool used to assess movement of a given structure against time. M-mode can be applied to confirm sliding of the pleura. When M-mode is applied across the pleural line, the ‘sea-shore’ sign is seen; so named as it represents the waves of the sea meeting the sand grains on the beach (figure 6).
- **A-lines**: A-lines represent reflection of the pleural line and are a key sign in normal lungs (figures 4 and 5).

**Figure 2** Point of care ultrasound (POCUS) probe selection.

**Ultrasonographic features of normal lung**

The key features of normal lung as seen on POCUS are outlined in box 1.

Failure to identify the normal signs, or the presence of additional signs suggest the presence of pathology. Take the whole clinical picture into account and remember that in lung POCUS, signs are less specific than they are sensitive: it is easier to exclude pathology than pick it up.

**CASES: LUNG POCUS IN ASSESSING AND MANAGING RESPIRATORY FAILURE IN THE CRITICALLY UNWELL CHILD**

We will now work through two cases to illustrate how POCUS can be used at the bedside to assess a child with respiratory failure.

First let us consider the common causes of respiratory failure in children (figure 7). Many features of lung POCUS will help differentiate this list.

**CASE 1: THE INFANT IN RESPIRATORY DISTRESS**

Louie is aged 3 months born at 32 weeks with a post-natal diagnosis of a large perimembranous ventricular septal defect. He is now term corrected.

He is awaiting corrective cardiac surgery and has been on twice-daily oral diuretics since his discharge from the neonatal unit a month ago. It is currently winter. Louie’s mother tells you he has been struggling...

**Figure 3** Image to show the key areas used in lung point of care ultrasound.

**Figure 4** Normal lung with linear probe (neonates and infants).
Best practice


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to gain weight, has become more breathless over the last 24 hours and cannot now complete feeds.

Differential Diagnosis

The clinical history and examination will provide a list of differential diagnoses. POCUS helps to narrow down and focus on specific differential diagnosis. Using the diagram of common cause of respiratory failure in children (figure 7), the most likely differential diagnosis for case 1 and the POCUS signs that help us differentiate between them are illustrated in figure 8.

Pulmonary Oedema

The features of pulmonary oedema on respiratory POCUS are displayed in box 2. In addition, findings on cardiac POCUS may also support the diagnosis of heart failure.

In pulmonary oedema, the sum of B-lines corresponds with the amount of pulmonary oedema. As pulmonary oedema improves (eg, with diuretics or positive pressure ventilation), the number of B-lines reduces. POCUS can help show the resolution of pulmonary oedema in real time, unlike the chest radiograph, which tends to be slower.12 If you see multiple B-lines, maybe the child does not need volume resuscitation.

Pulmonary Consolidation

It is well known that chest radiograph changes of pulmonary consolidation lag behind the clinical features; this is not the case with ultrasound. By scanning sequentially, you will identify lobar consolidation prior to its appearance on the chest radiograph.

The key features to identify pulmonary consolidation are outlined in box 3, and demonstrated in figure 10.

Case 2: The teenager with acute respiratory distress

James is aged 13 years with a past medical history of mild asthma. He is a keen footballer and was unable to attend training today due to being acutely short of breath unresponsive to his usual inhalers. He complains of non-specific chest pain.

Figure 5 Normal lung with curved-linear probe (older children and adults).

Figure 6 Normal lung on motion (M)mode (demonstrates the sea-shore sign).

Figure 7 Diagram of common cause of respiratory failure in children.
As with case 1, you can use the diagram of common cause of respiratory failure in children (figure 7) to help identify the most likely differential diagnosis for case 2 and then use the POCUS signs to help us differentiate between the causes (figure 11).

**Pneumothorax**

A pneumothorax is air in the pleural space, causing pleural separation; it is this separation that produces the change in ultrasound findings.

The features to identify a pneumothorax are described in box 4.

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**Box 2**  **Point of care ultrasound (POCUS) findings in pulmonary oedema**

- **Normal pleural sliding** (both visually and on motion-mode)—see Box 1.
- **B-lines**: these are dense white lines radiating down from the pleura into the lung parenchyma. They can extend to the edge of the screen, and move with the pleural sliding. It can be normal to see one or two of these lines (particularly in the transitioning neonate shortly after delivery) (figure 9). Multiple B-lines can represent pulmonary oedema, fibrosis, acute respiratory distress syndrome or transient tachypnoea of the newborn. As with all clinical assessments, you apply your POCUS findings of B-lines to the clinical picture.
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Figure 9  B-lines (representing pulmonary oedema in both these cases) demonstrated using a curved-linear probe in an older child (A) and with a linear probe in an infant (B).

**POCUS: THE HEART**

A critically unwell child with respiratory distress can present due to cardiovascular insufficiency and inadequate tissue oxygenation. POCUS cardiac assessment should be done in all critically unwell children to help you formulate a holistic assessment.

**Box 3  Point of care ultrasound findings in pulmonary consolidation**

- **The tissue-like sign:** lung looks more like solid viscera, such as the liver.
- **Dynamic air bronchograms:** air filled alveoli can appear echogenic due to dense consolidated surrounding lung.
- **Shred sign:** the deeper border of consolidated lung tissue that makes contact with the aerated lung is shredded and irregular.
- **Lung pulse:** the lung pulse is a phenomenon that is observed when the lung is not fully inflated. It is a measure of cardiac motion transmitted to the pleura through consolidated lung. In a ventilated patient, if seen with reduced pleural sliding, this can also indicate main stem bronchial intubation.

**Figure 10  Point of care ultrasound features of lung consolidation.**

**Box 4  Point of care ultrasound findings in pneumothorax**

- **Absence of pleural sliding:** seen and confirmed with motion (M)-mode.
- **No B-lines:** presence would exclude a pneumothorax.
- **Barcode or stratosphere sign:** the M-mode represents a static ‘barcode’ or ‘stratosphere’ sign; so named because there is no movement of the pleura with time (figure 12).
- **Presence of a ‘lung point’:** this describes the visualisation of the point that the visceral pleura start to separate from the chest wall parietal pleura. The lung point is highly specific; it can be hard to find without careful sequential scanning. This is the only sign that helps you ‘rule in’ a pneumothorax. (figure 12).

**Figure 11  Possible differential diagnosis for case 2 and the point of care ultrasound (POCUS) signs helpful in investigating this at the bedside.**
Cardiac POCUS is used to help answer three key questions to guide immediate resuscitation:

1. Is there a cardiac tamponade or extrinsic compression?
2. Is the child adequately filled (ie, adequate preload)?
3. Is the myocardial function normal?

Figure 15 describes the POCUS signs that allow you to answer these questions.4

These questions will be unlikely to identify specific congenital heart disease, nor is this a full echocardiographic assessment, but is designed to help guide further fluid resuscitation or inotropic support.

HOW TO GET TRAINING IN POCUS FOR THE PAEDIATRICIAN

Adult critical care-based ultrasound courses (Core Ultrasound in Intensive Care and Focused Intensive Care Echocardiography courses) are well established and part of ICM training. These all provide key skills in POCUS, although in the adult population.13

A number of tertiary centres across the UK provide regular paediatric echocardiography courses, with the focus on congenital heart disease.

Work is now ongoing to create a UK paediatric-specific critical care ultrasound course, curriculum and mentoring systems. Three pilot Children’s Acute UltraSound (CACTUS) courses have taken place.11

**Box 5  Point of care ultrasound findings in pleural effusion**

- **Visualisation of the fluid:** appears black, between the lung parenchyma and the soft tissues (figures 13 and 14).
- **PLAPS point:** the presence of lung edge floating within the dense black effusion (figure 12).
- **The QUAD sign:** shape drawn between the pleural line and the lung line (visceral pleura) at its deepest point, with the rib shadows either side.10

**Figure 12**  Pneumothorax on point of care ultrasound as demonstrated by absence of pleural line lung sliding on motion (M)-mode (barcode or stratosphere sign) with a curved-linear probe in an older child (A) and a linear probe in an infant (B). The lung point (point of separation of the pleura) is seen in (C).

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The key aspects to developing your POCUS skills are to have good initial training, regular hands-on scanning time and a mentor to help review and interpret your findings. Caution must be taken about using POCUS to make clinical decisions, without appropriate governance and mentoring. Your adult emergency medicine and critical care colleagues could form a good starting point for this.

Figure 13  Pleural effusion demonstrated using a linear probe in an infant.

Figure 14  Pleural effusion and the PLAPS point demonstrated using a linear probe in an infant.

Figure 15  Summary of additional questions that can be answered using cardiac point of care ultrasound in a child with respiratory distress. IVC, inferior vena cava.

Test your knowledge

1. The linear ultrasound probe is best used to scan which of the two following structures:
   A. Vessels
   B. The heart
   C. The lung in neonates/infants
   D. The lung in adolescents/adults
   E. The brain

2. Which one of the following ultrasound features suggests lung consolidation:
   A. Barcode sign
   B. Absence of a lung pulse
   C. A-lines
   D. PLAPS point
   E. Tissue-like sign

3. Which two of the following lung ultrasound features are normal findings during lung POCUS:
   A. Pleural sliding
   B. A-lines
   C. Multiple B-lines
   D. Shred sign
   E. Barcode sign

4. Which one of the following is a feature of a pneumothorax on lung POCUS:
   A. Presence of pleural sliding
   B. QUAD sign
   C. Sea-shore sign
   D. Lung point
   E. Tissue-like sign

5. Which two of the following features may you see after the endobronchial intubation of a neonate, on the unventilated lung:
   A. Presence of pleural sliding
   B. PLAPS point
   C. Barcode sign
   D. Lung pulse
   E. QUAD sign

Answers to the quiz are at the end of the references.
CONCLUSIONS

POCUS is an essential skill in adult emergency medicine and critical care; this should be the case in paediatrics too. The POCUS can help you determine key diagnoses and treatment options at the bed space, in real time and then assess the effect of your intervention. This article outlines the key findings you may encounter to help you differentiate the breathless child, but attendance at accredited training should be encouraged for all paediatric staff dealing with acute paediatric emergencies.

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REFERENCES


Answers to test your knowledge quiz

1. (A and C); 2. (E); 3. (A and B); 4. (D); 5. (C and D).