Framework for Neonatal Lung Ultrasound in the UK

List of abbreviations:
CACTUS: Children Acute Thoracic Ultrasound
FUSIC: Focus Ultrasound in Intensive Care
LU: Lung Ultrasound
SAFE-R: Sonographic Assessment of liFe-threatening Emergencies - Revised
RDS: Respiratory distress syndrome
TTN: Transient Tachypnoea of the newborn
MAS: Meconium Aspiration Syndrome
PDA: Persistent Ductus Arteriosus
BPD: Bronchopulmonary dysplasia
nARDS: Neonatal Acute Respiratory Distress Syndrome

Neonatal lung ultrasound is a very useful skill that could help to improve clinical care of sick neonates in neonatal intensive care and reduce use of chest X-ray.

Training:

Neonatologists performing this skill should either have had a formal accredited training (CACTUS, FUSIC) or be in training. Only accredited staff can make clinical decisions based on their lung ultrasound findings. Level of training (in training, supervised scan in training, accredited) should be documented on the LU report.

Governance Framework:

Developing a governance framework within each unit is essential to maintain patients' safety and avoid making clinical decisions based on inaccurate diagnoses. Performing LU does not preclude requesting chest X-ray when clinically indicated, as they may both be complementary, especially in case of suspected lung overdistension, or if the suspected anomaly might not be accessible with LU (behind shoulder blade, hilum).
This includes:

1- Formal structured reporting system, agreed with the neonatal governance group
2- Secure archiving system of all neonatal lung scans, discussed with radiology department
3- Peer review process with an identified mentor within the trust or network.

Equipment:

Most neonatal units will have ultrasound machines to perform cranial ultrasound as part of their routine neonatal care. Equipment should be disinfected before and after each scan using special disinfection wipes.

Probes:
Commonly used probes are curvilinear, phased array or linear. For best results in neonatal ultrasound, high frequency linear or microlinear (such as hockey stick) probes ranging from 8-20 MHz should be used. Small lower frequency curvilinear probe is recommended for scanning costophrenic angles to rule out effusion and for the emergency SAFE-R protocol.

Machine setup:

1. Use sterile warm gel for each patient.
2. Ask your ultrasound company provider to adjust lung ultrasound settings.
3. Suggested adjustments:

- 1-2 **focus** at the level of the pleural line
- **Depth** at 2-3cm (could be changed according to different patients and pathologies)
- **Time-gain compensation** set up to obtain uniform image
- Recorded loop should be 3-6 seconds long.
- **Fundamental frequency imaging**: do not use harmonics as they can decrease reverberation which are responsible for main LU artefacts (A and B-lines)
- **Speckle reduction imaging function**: turned on
- **Spatial compounding function**: turned off
- **Edge enhancement**: increase grayscale difference to increase subtle difference between adjacent tissues.

Indications of neonatal lung ultrasound:

a. Assessment of RDS and prediction of non-invasive ventilation failure and the need for surfactant.

2- Assessment of term/near-term infants admitted with tachypnoea (TTN/RDS/MAS/others)

3- Assessment of ventilated infants when required and after full clinical and equipment check:
   a. Increasing O_2 requirement
   b. Difficult ventilation with unexplained abnormal gas exchange
   c. Clinically suspected ventilator associated pneumonia (VAP)

4- Assessment of infants on non-invasive ventilation with significant increase of FiO_2, to look for (depending on clinical context):
   a. Consolidation and guide lung recruitment
   b. Signs of pneumonia
   c. Increased interstitial fluids from PDA and need for diuretics (for example for BPD patients)

5- Lung ultrasound guided recruitment for babies on invasive or non-invasive ventilation.

6- Assessment of pneumothorax and pleural effusion: diagnosis, semi-quantification, chest drain insertion and chest drain clamping.

7- Crashing Neonate (see Procedures below).

8- Endotracheal tube positioning

9- Other potential indications:
   a. Prediction of BPD by serial scans in the first 2 weeks of life.
   b. Assessment of readiness of extubation
   c. Assessment of diaphragmatic excursion.

Protocol of scanning:

Indication of the examination:

This should first be clarified and take clinical context and examination into account before starting.

Patient preparation:

Keeping the patient comfortable and settled is essential. Obtaining support from a bedside nurse or by other staff is preferable to maintain optimal level of comfort and reduce examination duration.

Infant's position should not be modified by the scan, and patient stability must be taken into consideration before starting:

- Scanning all lung areas might not be necessary if most accessible regions have already answered the clinical question.

- If the patient is supine, posterior areas will be examined by gentle mobilisation of the arms.
- If the infant is prone, and scanning anterior regions is still necessary to answer the clinical question, supporting staff will gently slightly rotate the body to allow sliding of the probe anteriorly.

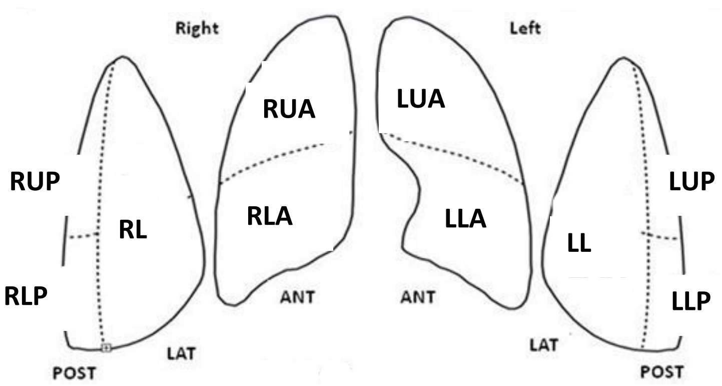
Both lungs should be completely scanned, from apex to thoraco-abdominal junction, using vertical and horizontal views.
For quicker labelling during scanning and reporting, the neonatal lung can be divided into 10 zones

Each lung is separated into 3 main regions: anterior, lateral and posterior.

- Anterior region is limited by the sternum and the anterior axillary line.
- Lateral region is located between anterior and posterior axillary line
- Posterior region extends between the posterior axillary line and the spine.

Anterior and posterior regions can be divided into upper and lower areas. Each area needs to be fully examined.

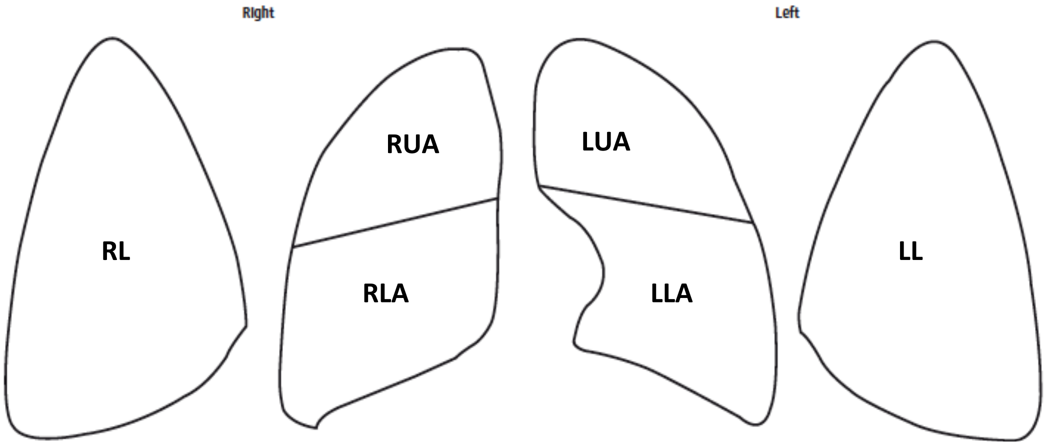
Figure 1: full examination



RUP: Right upper posterior
RLP: Right lower posterior
RL: Right lateral
RUA: Right upper anterior
RLA: Right lower anterior
LUA: Left upper anterior
LLA: Left lower anterior
LL: left lateral
LUP: Left upper posterior
LLP: Left lower posterior

It can be useful for each unit to choose and agree on acronyms for each view (as suggested above) for quicker labelling during scanning and reporting. However, there is currently no universal labelling. Operators can also decide to limit the examination to 6 zones, scanning easily accessible areas, if clinical questions can be answered from this limited examination or if the main reason for examination is lung ultrasound scoring.

Figure 2: 6 regions examination: lung scoring



Infants can be scanned supine as well as prone using the same technique.

Scanning technique:

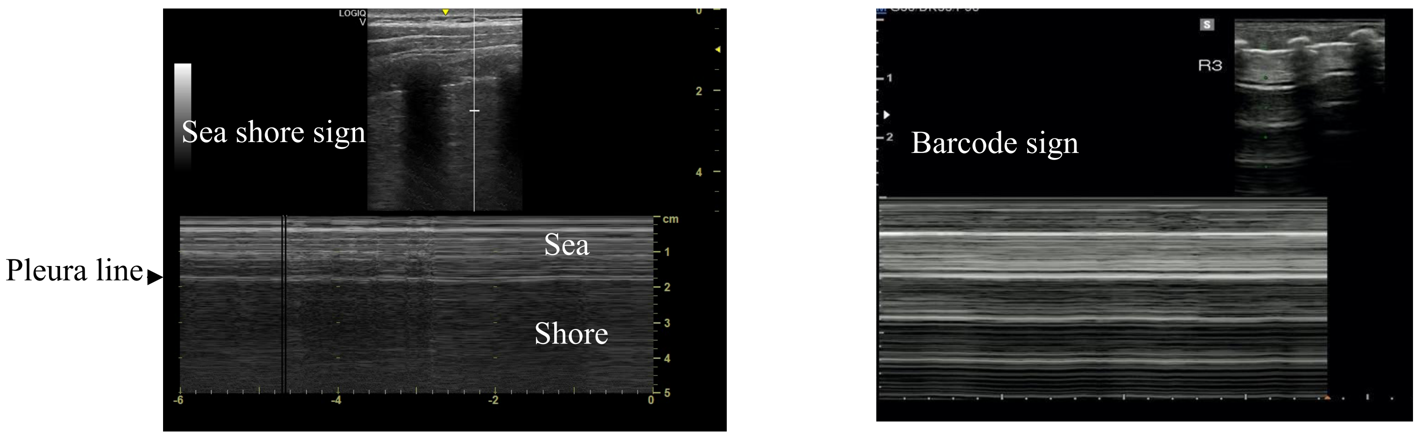
Each zone needs to be scanned vertically (longitudinal view) with the probe marker towards the baby's head, and if necessary (consolidation, lung point, pleural effusion….) horizontally (transverse view), with marker towards the right side of the patient (universal ultrasound convention).

Some teams have proposed a different orientation for the transverse view, with the marker turned inward or outward from the longitudinal view: this needs to be clarified and agreed within each team.

M-Mode:

M-mode could be used as a complementary technique to confirm the presence of a pneumothorax. Normal lung in M-Mode appears as the "seashore sign": the chest is static (the sea), and the lung is sliding (the shore). When a pneumothorax is present, M-Mode with cursor on the pathological area shows the "barcode sign" or "stratosphere sign", reflecting the absence of lung sliding: the "shore" disappears and the whole screen is "sea". See appendix for more illustration.

Figure 3: Seashore and barcode signs (M-Mode)



Specific findings in different neonatal respiratory disorders:

Transient tachypnoea of the newborn:

- Pleura: normal, thickened, or blurry with minimal irregularities. Subpleural consolidation are never>0.5cm width
- Double lung point (presence of coalescent B-lines in lower lung zones with spared, normal upper lung zones with A-lines dominance), present in 50% of cases and can be observed until 48h of age
- Numerous non-coalescent B-lines in one or both lungs
- Spared areas of normal lungs with A-lines and minimal B-lines.

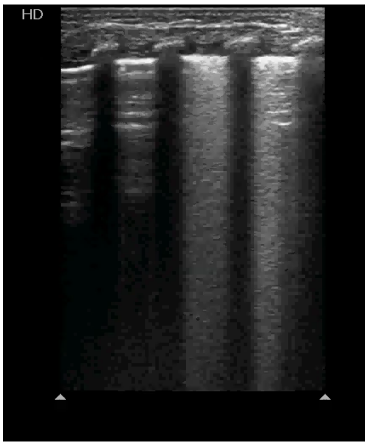


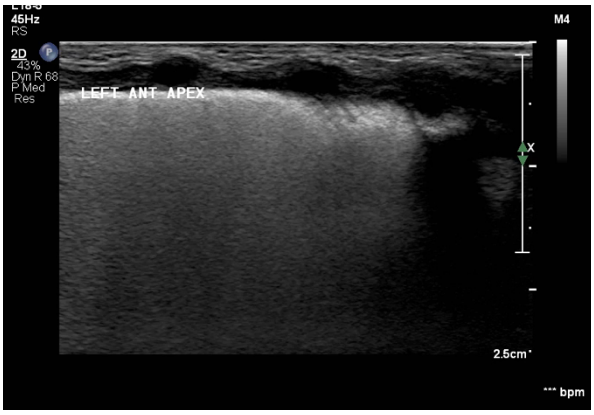
Figure 4: Double lung point

RDS:

Bilateral signs of:

- Pleural line abnormalities (thickened, irregular +/- subpleural consolidations)
- White lungs due to diffuse coalescent B-lines in all lung zones
- Absence of spared areas in all lung zones.

Figure 5: RDS



Bronchopulmonary dysplasia:

Bilateral and diffuse changes in the form of:

- Thickened and/or irregular pleural line
- Small subpleural consolidations/collapse

- Abnormalities are heterogenous and vary in severity from isolated B-lines to ‘white lung’
- Large consolidations with punctiform air bronchograms in dependant areas.

Pneumothorax:

- Absence of lung sliding with presence of A-lines only (A’ profile)
- Absence of B-lines in the affected area. Presence of a single B-line excludes the diagnosis of pneumothorax
- Presence of lung point (see Appendix/video library/pneumothorax/video 2)
- Absence of lung pulse
- Presence of barcode/stratosphere sign on M-mode.

Pneumonia:

- Pleural line abnormalities (absent sliding, disappearance, irregularities, disruption, and coarse appearance)
- Lung consolidation
- Presence of dynamic linear arborescent air bronchogram is highly specific of pneumonia
- Fluid bronchogram appearing as linear hypoechogenic area due to fluid exudate from inflammation and pus formation
- Shred sign: irregular/shredded borders of the lung consolidation, suggestive of non-trans-lobar consolidation.

Meconium Aspiration Syndrome:

Bilateral, diffuse and heterogeneously distributed lung abnormalities:

- Sub-pleural, non-translobar lung consolidations and atelectasis.
- Diffuse or focal areas of interstitial syndrome (presence of B-lines/comet tales) with various density alternating with spared areas
- Different patterns and distribution across both lungs.

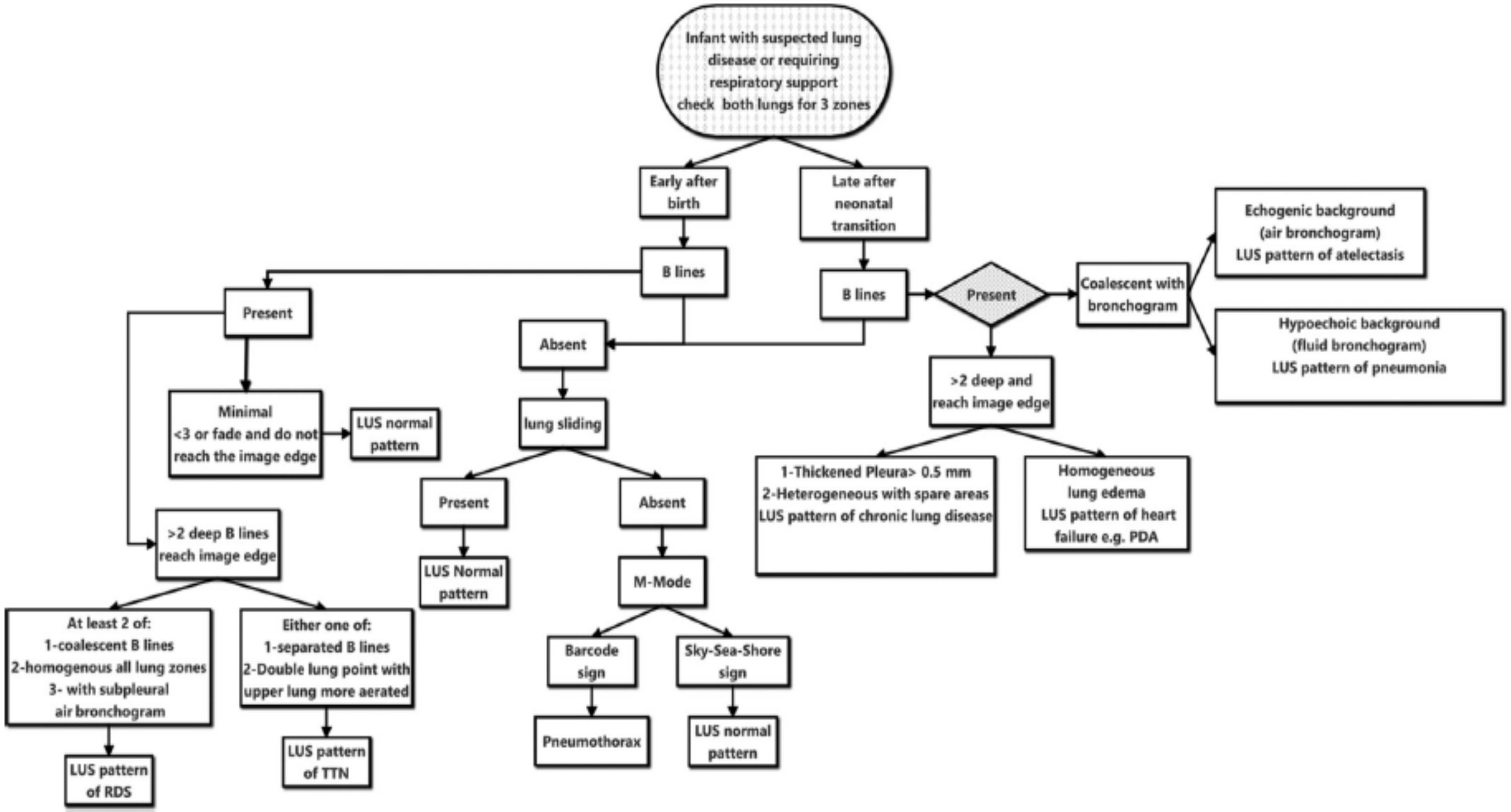
Pleural effusion:

- Anechoic area separating the 2 layers of the pleura.
- Sinusoidal sign on M-Mode
- It is recommended to specify when possible:
    a. Echogenicity of the fluid (homogeneously anechoic in transudate; hypoechoic with hyperechogenic dynamic images moving with gravity in exudate)
    b. Presence and size of consolidation facing the effusion (to differentiate large pleural effusion causing passive atelectasis and small effusion facing a pneumonic area)
    c. Whenever possible, measurement of the deepest effusion.

Suggested neonatal lung ultrasound algorithm for respiratory distress:

Clinical context and examination should always be the priority in the diagnostic process:

Figure 6: Algorithm for neonatal LU (El-Sayed et al. Neonatal Network. July 2018)



Procedures

US guidance for surfactant administration

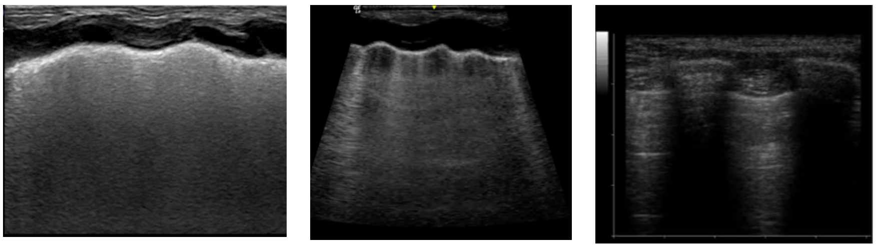
Two main LU tools have been published and assessed for diagnosis accuracy to guide surfactant administration: LU grading (qualitative) and LU score (quantitative). However, it is recommended that each NICU selects and agrees on which tool they will use to facilitate serial US comparison and decision making.

- **LU grading system:**

LU patterns have been defined as follow:

a. Type 1: white lungs: pleural line is defined, but blunted
b. Type 2: majority of B-lines, mixed with horizontal A-lines, sharp pleural line
d. Type 3: A-lines, sharp pleural line, no B-lines

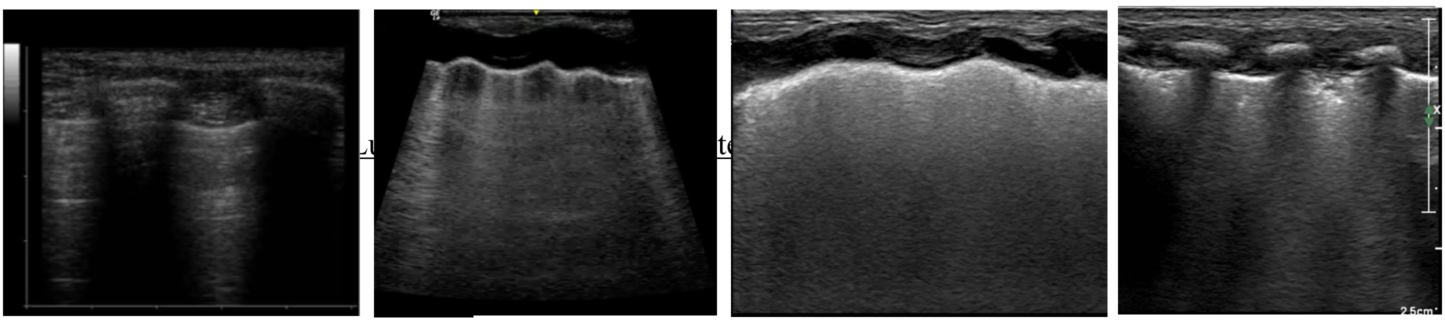
Figure 7: Grading system from Raimondi F et al, Crit Care. 2012 Nov 14;16(6)



Type 1 Type 2 Type 3

- **LU scoring system (Figure 2 and Figure 8):**

As described by Brat et al, for each lung area, a 0- to 3-point score was given (total score ranging from 0-18). The LUS score described the total spectrum of possible conditions (a normal aerated lung, an interstitial pattern, an alveolar pattern, and consolidation) (Figure 8).



Score 0 Score 1 Score 2 Score 3

Score 0 = Normal aerated lung with predominance of A-Lines
Score 1 = Interstitial syndrome >3 separated B-Lines.
Score 2 = White lung (coalescent B-lines)
Score 3 = Thickened pleural line, subpleural consolidation with air bronchogram and coalescent B lines

Therefore, minimal score is 0 and maximum score is 18:

Based on the best and most recent evidence, suggested cut-off for surfactant administration is 9

From 2 meta-analysis and a recent multicentre study, persisting white lungs pattern at 2 hours of life or LU cut-off score of 9 or more have been associated with an excellent diagnostic accuracy to predict CPAP failure and need for surfactant administration. When performed soon after birth, LU allows a timelier surfactant administration (within 2-3h of age) and decreases oxygen exposure.

US guidance for chest drain insertion

US prior to chest drain insertion has been shown to decrease complications in adults and is recommended by experts (British Thoracic Society). It allows to:

- Identify important anatomy (diaphragm, liver, spleen)
- Identify loculated spaces/lung
- Assess the depth of the pleura

However, it will not identify the neurovascular bundle.

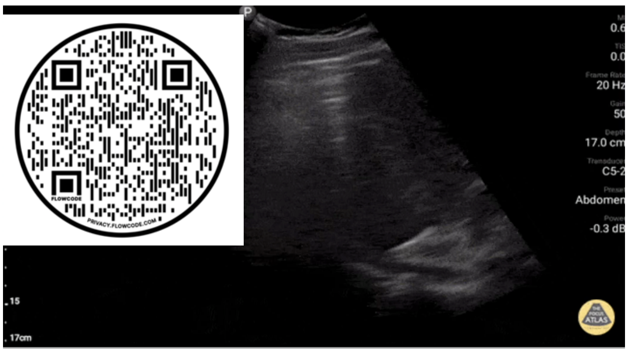
Summary of the technique is as follows:

1. Position the baby as usual for pleural effusion or pneumothorax drainage:

Figure 9: patient positioning

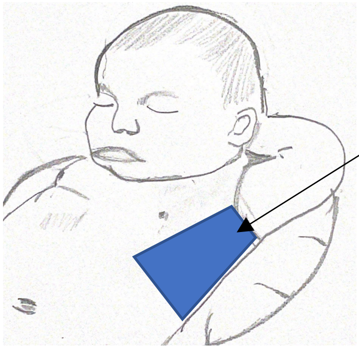
2. Identify the level of the diaphragm: look for the **curtain sign**. This level is the lower limit of the safe zone for drainage. The upper border is the axillary area.

Figure 10: Lung curtain sign, from https://thepocusatlas.com

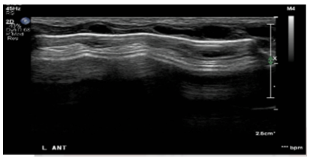


3. Confirm the presence of the pneumothorax or the effusion within the safe zone.

Figure 11: identification of the safe zone for drainage



- Safety area for chest drain insertion
- Confirm pneumothorax/effusion in this area on 3 dimensions



4. Chest drain can be inserted within the safe zone, following local unit guideline.

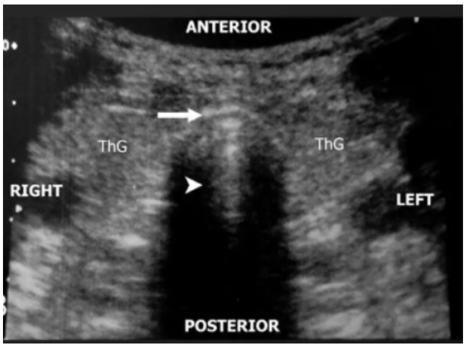
Endotracheal tube positioning using US

Endotracheal position of the ETT is a clinical diagnosis confirmed by clinical examination and end-tidal CO_2 detection in exhaled gas.
In some complex and exceptional situations, US can also exclude oesophageal intubation. More routinely in NICU, it can also confirm the endotracheal tube positioning.

Technique to exclude oesophageal intubation:

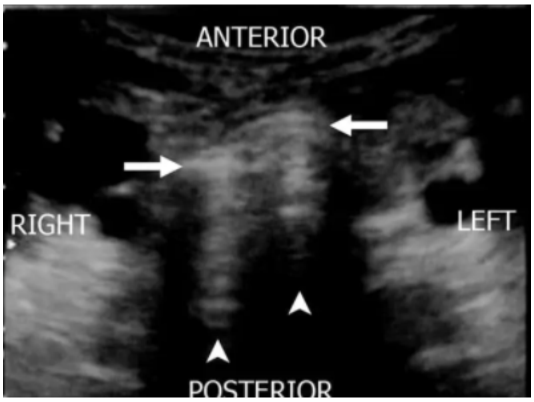
1. Select semi-convex or phased array probe
2. Position the probe transversally at the suprasternal notch
3. Look for posterior reverberation (headed arrow). This is the normal view of the trachea with only 1 visible air-mucosa interface (1 headed arrow):

Figure 12: Normal view of the trachea



4. Check to see that there are no 2 air-mucosal interfaces (2 headed arrows) indicating ETT is in the oesophagus as per image below (only 1 air-mucosa interface should be present):

Figure 13: Oesophageal intubation

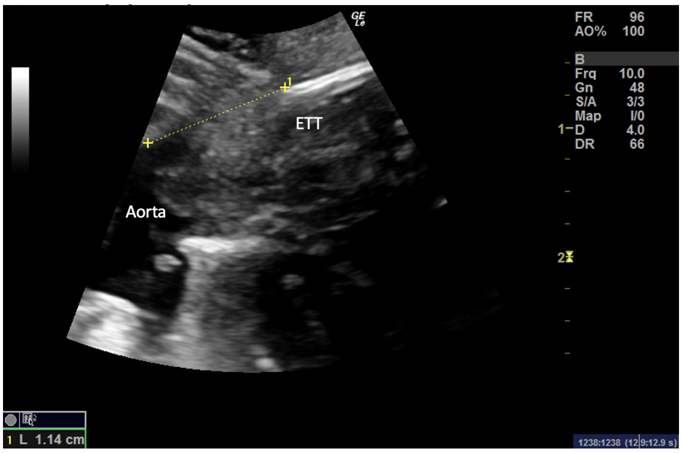


Technique to assess correct distance of the ETT to the carina:

This can be evaluated using a surrogate measurement: distance between the ETT tip and the upper border of the aortic arch.

1. Select semi-convex or phased array probe.
2. Position the probe at the right upper border of the sternum with the marker at 12 O'clock. Probe is then slightly tilted toward the left side of the patient until the ETT image is visualized. It appears as a double rail image. To confirm the ETT tip is well visualized, a second operator performs small movements of the ETT tube: this tip should also be moving.
3. The aortic arch is then visualized and the distance between the ETT tip and the upper border of the aortic arch is measured: **optimal distance is 1cm**.
4. If the ETT cannot be visualized, it is either too high, or you need to exclude a pneumothorax.

Figure 14: Measurement of the distance between the ETT tip and the upper border of the aortic arch

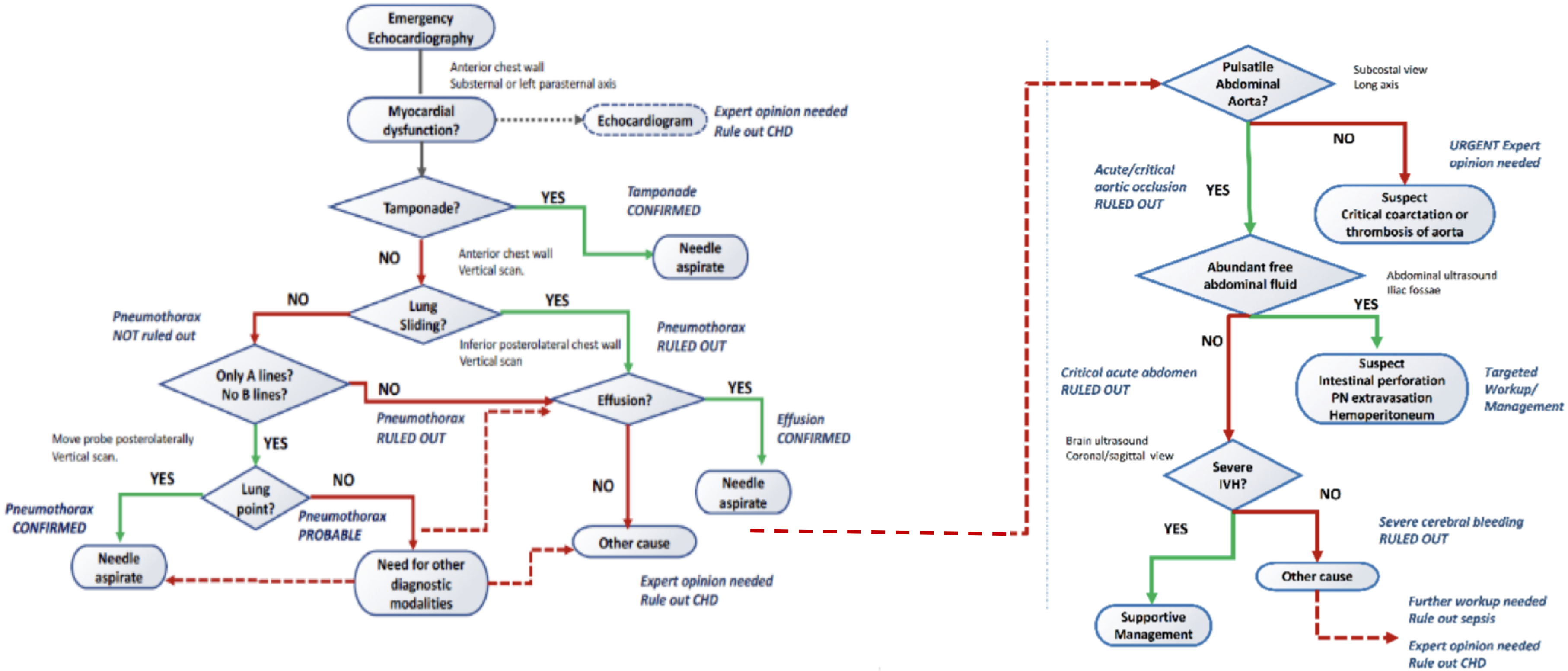


Emergency POCUS algorithm for the crashing neonate (SAFE-R protocol):

Objective: To rule in and rule out main treatable causes of acute deterioration in neonates.

Principle: A single US probe (semi-convex or micro-convex are preferred) is used to scan multiple areas of the infant body. It is mandatory to have performed usual full clinical examination as well as equipment check before starting scanning the patient.

Figure 15: SAFE-R protocol



Appendix of Supplementary Materials

Video Library

1- Normal lung ultrasound:
https://youtu.be/-XKPCugsg2w

2- TTN:
Video 1: https://youtu.be/6eRKrqyidDY
Video 2 (with double lung point): https://youtu.be/UD0EQ0k4ADQ

3- RDS:
Video 1:https://youtu.be/U_4KxOVRTCo
Video 2: https://youtu.be/MUn6ptEAuII

4- Bronchopulmonary dysplasia:
https://youtu.be/rKIsiwecA7A

5- Pneumothorax:
Video 1: https://youtu.be/5tzCK65BSdc
Video-2 (lung point): https://youtu.be/ZUhUv5sGysE

6- Consolidation/collapse:
https://youtu.be/HPutCFNy7Ds

7- Pneumonia:
Video 1: https://youtu.be/5yi7hmgYKkM
Video 2: https://youtu.be/srlwofG0QeM
Video 3: https://youtu.be/xEw7HAAv5-4

8- Pleural effusion:
https://youtu.be/b4GL2eRkn_s

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