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PACSA SUPPLEMENT

Point-of-care ultrasound in neonatal anaesthesia – current applications and future practice

MW Gibbs

Department of Anaesthesia and Perioperative Care, Groote Schuur Hospital, University of Cape Town, Cape Town, South Africa
Corresponding author, email: matthew.gibbs@uct.ac.za

Point-of-care ultrasound (POCUS) is a widely accepted and used modality across many fields of medicine, particularly in anaesthesia. Ultrasound devices with improved image quality and mobility as well as reduced cost and size have made POCUS widely available, even in resource-poor settings. Many adult protocols have been adapted for neonatal use, as ultrasound is easily able to visualise neonatal organs and vessels. Functional or focused echocardiography is routinely performed in many institutions, with many bedside applications including central line placement, peripheral and arterial line placement, lung ultrasound and endotracheal tube localisation.

Introduction

Point-of-care ultrasound (POCUS) is an accepted standard of care imaging modality that is used across many fields of medicine, in fact, any specialisation where time-sensitive information is required for patient care.[1-3] Neonatology and paediatrics no less so, and paediatric anaesthetists are using POCUS in day-to-day practice at an ever increasing rate. Due to decreasing costs, increased imaging power and portability of various devices on the market, the newly fledged paediatric anaesthetist needs to rapidly become expert with evidence-based application of POCUS in their practice. Particular use may be found during central line placement, peripheral line placement, cardiac function assessment, diagnosis of pneumothoraces and endotracheal tube localisation, amongst others.

Figure 1. High frequency linear probe – A small footprint aids handling and visualisation in small neonates

Central venous access

Figure 2. Internal jugular vein above smaller artery. Abnormal anatomy is often visualised on routine scans.

Figure 3. With pressure applied by the probe, the internal jugular vein collapses easily. The nearby artery remains patent, and in some circumstances may become more prominently pulsatile.

A variety of central vascular catheters may be placed in neonates, including umbilical artery catheters, umbilical venous catheters, peripherally inserted central catheters and central venous catheters. Besides facilitating placement, ultrasound (US) may be used to confirm correct tip placement. Tip placement by standard chest radiography may be imprecise due to the doming of the diaphragm. One study in very low-birth-weight newborns showed that when the catheter tip was interpreted by X-ray as located in the vena cava-right atrium junction, 8/29 (28%) were in fact in the left atrium by echocardiogram.[1] US allows direct visualisation of umbilical, peripherally inserted central catheters (PICC) and central venous catheters, more accurately confirms correct placement and without the risks of ionising radiation.[2,3] Doppler also allows identification of vessels and associated anatomy.

The best insertion and maintenance technique of central venous catheters in small babies is a debatable subject, as smaller vessel and catheter diameters imply increased technical difficulties. Although space when operating is limited, US does allow the identification and use of vessels not normally identified by landmark techniques alone. US is useful for identifying the internal jugular vein (IJV) in neonates, but there are no large studies showing any significant advantage.[4] It may be useful to still use US to mark the position of the vein, but when doing a real-time cannulation, the operator must be aware of the effect of the probe on the collapsibility of the IJV (compare Figures 2 and 3), especially in the shocked premature neonate. The needle may be advanced under the probe either out-of-plane (where the needle crosses the US beam perpendicularly) or in-plane, where the entire needle remains in view at all times (see Figures 4 and 5).[5]

The brachiocephalic in-plane US guided technique used by Breschan is useful, as the targeted vessel tends to maintain its diameter in hypovolaemic and shocked patients.[6] During a seven-year period, the technique described in their 2018 paper resulted in successful cannulation of the brachiocephalic in 94% of patients (weights between 590 g and 2 500 g), with only one attempt necessary in 70% (100/142). The left brachiocephalic appears easier to cannulate due to its more horizontal appearance and allows an in-plane needling technique, as demonstrated in Figures 6 and 7.

Figure 4. Out-of-plane approach revealing guidewire in-situ

Figure 5. In-plane approach, guidewire correctly positioned in a vessel

Figure 6. Left brachiocephalic vein with doppler

Figure 7. Left brachiocephalic vein

Arterial access

No matter how experienced an anaesthetist is, arterial cannulation in neonates can be dishearteningly challenging. The target, even in larger infants is depressingly small: even at one year of age, the average short axis diameter is 1.7 mm, 1.6 mm and 1.2 mm for the posterior tibial, radial and dorsalis pedis arteries respectively.[7] US has revolutionised the placement of arterial lines, in both adults and children. For arterial line placement in adults, US has been shown to improve first pass success rates (RR 1.55; 95% CI, 1.02–2.35).[8] A meta-analysis of four randomised controlled trials (345 patients) in small children and infants demonstrated a significantly increased first-attempt success rate (RR 1.94, 95% CI, 1.31 to 2.88, P = 0.001) when using ultrasound to guide arterial access.[8]

Cardiac

Cardiac point-of-care US is an extension of a standard physical assessment and seeks to be brief, and address a specific clinical question, usually binary in nature. It is not a replacement for a cardiology assessment or detailed structural echocardiogram. It is one of the more common applications of POCUS and allows for frequent serial assessments of haemodynamics during the perioperative period. It is well established in adult medicine,[9] the accuracy of non-cardiologist evaluation of myocardial function and haemodynamics is high[10] and has now become an accepted part of the armamentarium of the neonatologist.[11]

Rather than looking at a detailed anatomical analysis, neonatal cardiac POCUS concentrates on helpful real-time measures of haemodynamics such as ventricular function, volume assessment and cardiac filling. The presence of a patent ductus arteriosus may also be sought. Qualitative measures of contractility along with quantitative fractional shortening measurements may be quickly determined in a deteriorating patient. Good views are usually simple to achieve due to thin thoracic walls.

When cardiologists are not available on site or after hours, targeted cardiac ultrasound may be critical to the management of the unstable neonate, especially as serial evaluations of an evolving illness may be made. There is limited data on the overall effect of functional cardiac ultrasound on neonatal outcomes, but there is certainly much anecdotal reporting of benefit in the setting of acute cardiorespiratory collapse.[12] A retrospective study of 199 neonates in a Canadian neonatal intensive care unit who underwent 512 targeted neonatal echocardiograms showed a change in clinical management in 212 cases (41%) and avoidance of a planned intervention in 112 cases (22%).[13] Extending targeted echocardiography to the perioperative phase by anaesthetists is logical but there is a need for standardisation of training and quality assurance.[14] The anatomical assessment of the complex congenital heart lesion should remain the domain of the cardiologist but it is equally important to recognise normal patterns to know when to suspect the presence of a congenital heart lesion.

Lung

Lung US has been well established in adult medicine and is a proven aid in diagnosis and management of critically ill patients.[15–17] It can be performed quickly, with virtually any probe available and has a higher diagnostic accuracy than physical examination and chest radiography combined.[18] It is relatively easy to learn and appropriate for use in all perioperative areas. Other advantages include a reduction in the cost of image acquisition and exposure to ionising radiation as well as decreased time to interpretation of images and appropriate therapy. Given the large change in acoustic impedance as US waves penetrate the air/tissue interfaces of the lung, most waves are reflected back to the probe, meaning that only artifacts may be seen. It is the interpretation of these artifacts and recognition of particular patterns that allows the appropriate diagnosis to be made. A recent publication by Neethling et al. provides a more detailed explanation of how to incorporate lung US in the South African context.[17]

In neonates, the thin chest wall and shallow chest cavity as well as a cartilaginous sternum allow very detailed views to be made with high resolution linear probes (10–15 MHz). Alternatively, a micro-convex probe may also be used, and can be easily applied between the ribs. There are no pathophysiological reasons for different signs in neonates, and the standard signs can all be defined in the critically ill neonate: A-lines, lung sliding, pleural effusions, B-line artifacts and the lung point indicating a pneumothorax.[19] Table I briefly summarises the normal and abnormal signs that may be identified. A number of lung US protocols exist, allowing a standardised approach to lung pathology, such as the Bedside Lung Ultrasound in Emergency (BLUE) protocol. In the adult, it can help diagnose six major pathologies seen in 97% of patients within three minutes.[18] This may be adapted for neonatal use. There are characteristic patterns associated with pneumonia, transient tachypnoea of the newborn and respiratory distress syndrome.[20]

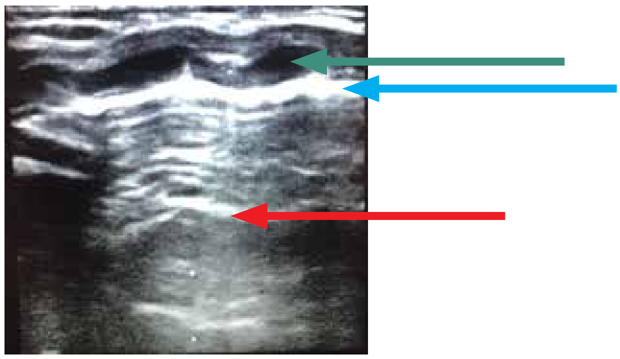

Figure 8. Lung ultrasound: Green arrow: ribs; Blue: pleura; Red: A-lines

As in adults, all neonatal lung ultrasound signs arise from the pleural line, which can be recognised as a hyperechoic line between the rib shadows. This is usually referred to as the 'bat' sign. Six standardised points of analysis are sufficient for use in point-of-care protocols: two anterior and one semi-posterior/lateral bilaterally. The operator must be able to recognise normal lung tissue using certain standardised artefacts or signs. Regular horizontal lines, usually equal to the skin-pleural line distance, are referred to as 'A-lines' and represent normal lung tissue (see Figure 8). Because the lung is constantly moving, lung 'sliding' may be seen: this is the shimmering appearance of the visceral and parietal pleurae as they rub over each other, also known as the 'line-of-ants' (see supplementary materials video 1). M-mode is a powerful addition to the examination, with the recognition of the 'seashore' sign. A regular pattern appears above the obvious pleural line (skin/fat/muscle tissue has no dynamic movement

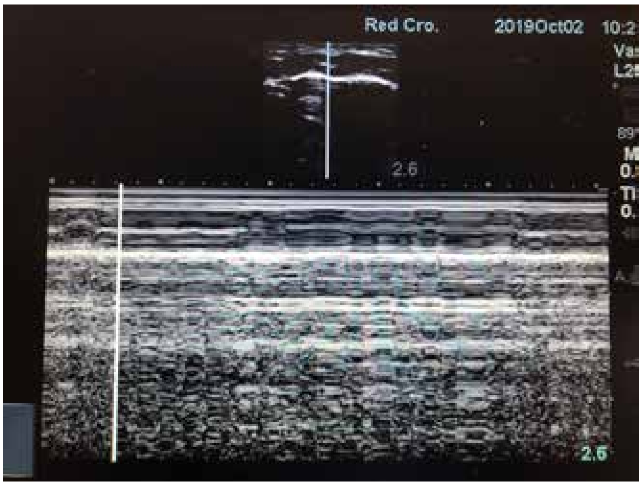

Figure 9. Lung US M-mode: Sandy beach sign

during the respiratory cycle) with a 'sandy beach' appearance below the pleural line, as there is permanent movement of the pleura and lung tissue (see Figure 9).[21]

The timeous recognition of a pneumothorax, either spontaneously, during surgery or after central line placement, is key to instituting treatment. Lung US is well suited to this as a sliding sign rules out a pneumothorax, whereas if a 'lung point' is identified, it is 100% specific for the presence thereof.[22] A lung point is the specific area where the visceral and parietal pleural surfaces separate when a pneumothorax forms. This point is dynamic and shifts during the respiratory cycle and may be seen alternating between the 'sandy beach' and 'stratosphere' or 'bar-code' signs.

Pleural effusions are easy to identify and as little as 50 millilitres of fluid may be identified. It is important to recognise interstitial syndrome in the critically ill neonate. B-lines, also known as comet-tail artefacts, are artefacts that are generated by the juxtaposition of alveolar air and septal thickening (usually from fluid or fibrosis) and indicate either pulmonary oedema (either cardiac failure or acute lung injury), interstitial pneumonia or lung fibrosis. These long, vertical hyperechoic lines diagnostically continue to the edge of the ultrasound screen, arise from the pleural line, erase A-lines and move with lung sliding.

Table I. Normal and abnormal lung ultrasound signs

Normal	Abnormal
Lung sliding or 'line of ants'	Absence of lung sliding
Lung pulse: If the pleural layers are still adjacent, cardiac pulsation will be transmitted to the pleura by the lung	Lack of lung pulse
A-lines	B-lines/comet-tail artefact Indicative of interstitial syndrome
M-mode: Seashore sign 'Sandy' pattern below pleural line Regular pattern above pleural line	M-mode: Stratosphere sign/ Bar-code sign Regular pattern above and below pleural line No movement at the level of the pleura
	Lung point Alternating stratosphere and seashore signs Change of pattern during respiratory cycle as lung moves in and out of field
	Pleural effusion – hypoechoic fluid above the diaphragm; the tip of lung may also be seen

Lung US has additionally been used to predict surfactant need in preterm and extremely preterm neonates.[23] In a study of 133 infants (mean weight 1 043 g), a simplified lung ultrasound score (LUS) adapted from adult critical care guidelines significantly correlated with oxygenation index ($\rho = 0.6$; $P < .0001$) could be used to accurately predict the need for the first surfactant dose (area under the curve = 0.94; 95% confidence interval: 0.90–0.98; $P < .0001$).[24] This LUS was calculated after scanning with a high-resolution linear probe in upper anterior, lower anterior and lateral chest area bilaterally. Each area was scored from 0 to 3: 0 indicated an A pattern (only normal A-lines present), 1 a B pattern with alveolar-interstitial pattern and ≥ 3 well-spaced B-lines, 2 a severe B pattern (crowded B-lines) and 3 an extended consolidation (size > 1 cm). An overall score of 8 increased the probability of surfactant replacement to 92%. Each lung US took on average three minutes to perform.

Lung US has also been used to differentiate between transient tachypnoea of the newborn, meconium aspiration syndrome, pneumonia and respiratory distress syndrome.[25] Lung US may not completely replace chest radiographs but it offers significant time-sensitive information and may be of particular use to the perioperative physician during resuscitation where the early detection and management of pneumothoraces and pleural effusions may be life-saving. Ongoing research and the requisite training are required to further delineate the role of point-of-care lung ultrasound in neonatal anaesthesia.

Intubation

Neonatal intubation remains a challenge even with the advent of videolaryngoscopy. The rate of erroneous mainstem intubations can be as high as 30% in older children and 7% in the neonatal population.[26] The standard confirmation of endotracheal (ETT) intubation remains the chest X-ray, which is limited by availability, ionising radiation exposure and repositioning. However, determining intra-tracheal versus intra-oesophageal placement can be readily discerned with US. More than 80% of ETT tips may be visualised by ultrasound alone. A prospective study from 1986 in 16 infants, showed an ultrasound visualisation rate of 86%, and a close correlation between the distance of the ETT tip to the aortic arch on US and the distance of the tip to the carina on XR ($r = 0.8$).[27]

In neonates, a midsagittal suprasternal view is most useful for endotracheal tube verification and appears comparable to X-ray and capnography in determining ETT position in this population. Sagittal and axial images were obtained in a local setting in Bloemfontein, where a feasibility study was performed demonstrating the use of ultrasound in intubated neonates.[28] If positioning is not satisfactory at the time of US examination, adjustments can be made in real time and subsequently confirmed by bedside US. If a direct view of the ETT tip is not possible (usually due to a poor midsagittal suprasternal window), then examining for bilateral lung sliding using a probe bilaterally in the midaxillary or midclavicular lines can be useful.[29] By defining a 'deep' ETT as less than one centimetre above the apex of the aortic arch by US, a paired trial by Chowdhry et al. using 56 US and XR image pairs from 29 neonates had a sensitivity of 86% and specificity of 96% for identifying deeply positioned ETTs. There is also evidence that US visualisation of a saline-filled ETT cuff may increase sensitivity and specificity.[30] A transverse substernal/subxiphoid view can also be used to evaluate bilateral diaphragm motion – however this view only assumes intubation has been successful.

Old technology, new applications

Cranial sonography is widely used in the point-of-care evaluation of infants. A recent prospective observational study of thirty infants undergoing cardiac surgery examined whether transfontanelle ultrasound could predict fluid responsiveness.[31] The authors hypothesised that the respiratory variation of internal carotid artery blood flow peak velocity could predict response to a 10 ml.kg-1 bolus of crystalloid. A single experienced operator performed transfontanelle ultrasound using a high-frequency transducer (5 to 8 MHz), examining the internal carotid artery as well as aorta blood flow peak velocity and stroke volume index. Fluid responders (57% of patients: as measured by an increase in stroke volume index of > 15%) had an internal carotid artery variation of 12.6 ± 3.3% prior to the bolus, and the resultant receiver operative characteristic (ROC) curve was 0.828 (P < 0.0001; 95% CI, 0.647 to 0.940). A measure of pulse pressure variation and central venous pressure, however, had ROC curve values of 0.52 (P = 0.854; 95% CI, 0.33 to 0.71) and 0.66 (P = 0.140; 95% CI, 0.47 to 0.82) respectively.

Other perioperative uses of neonatal POCUS also include the diagnosis of necrotising enterocolitis (NEC)[32] and the placement of caudal needles and catheters.[33,34]

Conclusion

The presence of a point-of-care ultrasound device has become ubiquitous in many theatre suites and has many applications in the perioperative management of the sick neonate. There is urgent need for expanded standardised training as well as adequate quality assurance and the support of local paediatric cardiologists and echo technicians is imperative.[14]

Anaesthetists must still be aware of the limitations of their skills and the technology that they use; use it as an extension of their own clinical skills and refer to other specialists as necessary. However, as the evidence base increases, and clinicians become more familiar with ultrasound, widespread adoption of POCUS in neonatal anaesthesia will inevitably occur.

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