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REGULAR ARTICLE

Feasibility and utility of portable ultrasound during retrieval of sick term and late preterm infants

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ABSTRACT

Aim: To determine the role of clinician performed ultrasound (CPU) during the retrieval and transport of critically ill term and near term newborns.

Methods: A neonatologist with portable ultrasound accompanied a sample of newborn retrievals to perform cardiac and cerebral ultrasound before and after transportation.

Results: A total of fifty-five babies were studied. Median birthweight: 3350 g (2220–5030 g). CPU led to a change in the planned receiving hospital in ten babies. Eleven babies were suspected congenital heart disease (CHD) prior to retrieval: eight confirmed CHD by CPU and three normal structure. One transported to a children's hospital for cardiology review was confirmed as having normal structure; one to a perinatal hospital where normal structure was confirmed and one baby died at the referring hospital and postmortem confirmed normal structure. In five babies with clinical pulmonary hypertension, CPU revealed unsuspected CHD. The destination was changed to a paediatric cardiology centre, avoiding a second retrieval. Eleven babies had evidence of haemodynamic compromise allowing targeting of inotropes.

Conclusion: This is the first study of CPU during retrieval of high-risk infants. Ultrasound in retrieval is feasible, allows accurate triage of babies to cardiac centres and may allow more accurate targeting of fluid and inotrope support.

INTRODUCTION

Clinician performed ultrasound (CPU) is now used in many neonatal intensive care units (NICUs) to assess the transitional circulation, myocardial function, the ductus arteriosus, pulmonary artery pressures, pulmonary and systemic blood flows and for cranial ultrasound screening of intracranial blood flow and pathology in the sick newborn (1–4). CPU can also lead to the early recognition of the structurally abnormal heart that requires further assessment by a paediatric cardiologist (1).

In Australia, there is an accredited training programme for neonatologists run through the Australasian Society of Ultrasound Medicine (5). This course involves an online physics course and bedside training with completion of a logbook of scans of the neonatal cardiovascular and cranial systems (5). To date, 55 neonatologists in Australia and New Zealand hold this qualification or Certificate in Clinician Performed Ultrasound (CCPU) which requires resubmission of logbooks every three years to maintain competency. Outside of tertiary care in Australia, there is limited or no access to paediatric cardiology or neonatologists qualified in CPU. The CCPU is not a qualification in screening for congenital heart disease but in assessing normal structure and then function. Where normal structure is not confirmed, it is the responsibility of the CCPU qualified neonatologist to refer the baby to a paediatric cardiologist for review (5).

Some of the sickest babies are born outside tertiary hospitals and require transport to an NICU. It had been our experience that these babies are at particularly high risk for haemodynamic pathology when assessed with cardiac ultrasound on arrival at the tertiary NICU. Ultrasound machines are now portable, making it possible to

Key notes

- Capillary return and blood pressure are unreliable markers of systemic blood flow in the critically ill newborn and ultrasound adds to their comprehensive haemodynamic assessment.
- Ultrasound is feasible and useful in the retrieval of the critically ill newborns, adds to the diagnostic capabilities and facilitates the targeting of therapy
- Ultrasound can be integrated into the assessment of critically ill newborns requiring retrieval to tertiary care

carry and perform ultrasound assessment at the referring hospital prior to transport. The Neonatal Ultrasound in Transport (NUiT) study was conceived to assess the feasibility and potential clinical value of using CPU on newborn transport. The aims were to determine the prevalence and nature of haemodynamic problems in a cohort of newborns requiring mechanical ventilation and early postnatal transfer to a NICU and to quantify how often point-of-care ultrasound at the referring hospital might change the management or destination of a transport if structural heart disease is found. This study reports the experience in the cohort of babies born at term or near term who were likely to require mechanical ventilation in retrieval. The data collection in babies born before 30 weeks is currently concluding and will be described in a separate paper.

METHODS

This was a prospective observational cohort study performed by the Newborn and paediatric Emergency Transport Service (NETS), which serves 254 hospitals across New South Wales and the Australian Capital Territory providing transport for newborns requiring intensive care in ten tertiary perinatal hospitals and specialist children's hospitals. This is an area of 800 628 km^2 with a population of almost 8 million people (6). NETS teams comprise a specialist intensive care nurse and doctor travelling by road ambulance, fixed wing aircraft or helicopter. NETS performs an average of 750 emergency newborn transports each year of which approximately 100 require mechanical ventilation (7). Regional and metropolitan referring hospitals in Australia do not employ neonatologists but paediatricians, who usually do not have point-of-care ultrasound skills.

Referrals to NETS for possible transport were assessed by the NETS consultant for eligibility for the NUiT study after discussing the patient with the referring hospital. When available and cleared of clinical in-hospital duties, a research retrieval neonatologist with a Certificate in Clinician Performed Ultrasound (CCPU) – (Neonatal) (KC from 2007 to 2015 or TL from 2012 to 2015) accompanied the transport team with ultrasound equipment. Inclusion criteria: Babies were eligible if they were likely to require mechanical ventilation for transport, an ultrasound trained retrieval neonatologist was available and the mode of transport did not preclude a third team member. Exclusion criteria: Babies unlikely to require mechanical ventilation in transport, an ultrasound trained neonatologist was unavailable or the mode of transport precluded a third team member. To maintain the observational nature of the study, it was decided *a priori* within the protocol that the ultrasound findings would not be used in the management of a baby unless there might be significant clinical implications to withholding that information or the planned receiving hospital was deemed inappropriate, such as after ultrasound recognition of unsuspected major congenital heart disease or evidence of significant haemodynamic compromise. The goals of this study were as follows: (i) to explore the feasibility of the use of point-of-care ultrasound during neonatal transport, (ii) to document the incidence of clinically unsuspected circulatory compromise as defined by low ventricular outputs and ultrasound evidence of hypovolaemia or poor myocardial function, (iii) to document the incidence of clinically unsuspected congenital heart disease and (iv) documenting the resistive index in babies with hypoxic ischaemic encephalopathy and hypoxic respiratory failure.

Ultrasound protocol

On arrival at the referring hospital, parental consent was obtained to perform the studies utilising the GE Vividi® laptop ultrasound scanner (8). Ultrasound studies were conducted following stabilisation of the patient by the NETS team at the referring hospital and, when feasible, following arrival at the receiving hospital. Each assessment took around 15 minutes and was performed, as far as possible, without interfering with the activities of the retrieval team. If structural heart disease was identified by the researcher, the preliminary findings were reported to the clinical team including the receiving hospital team and the baby was transported to a children's hospital with paediatric cardiology services on site.

Cardiac ultrasound studies

Assessment of normal structure and connections, right ventricular output (RVO) with normal defined at >150 mL/kg/min, pulmonary artery pressures (PAP), superior vena cava (SVC) flow (normal defined as >50 mL/kg/min) (9) and direction of the shunt through the patent ductus arteriosus (PDA) were documented using referenced methodology (10–14). The measures of systemic blood flow (SVC flow and RVO) have been correlated with adverse outcomes in neonates (15,16).

Cerebral ultrasound studies

Sagittal views of right and left ventricles, a coronal sweep and assessment of the resistive index (RI) in the right and left middle cerebral arteries. The RI was calculated as the ratio between the end diastolic and peak systolic velocity, measured within the anterior or middle cerebral artery by duplex sonography (17).

Demographic data including the birthweight, type and timing of delivery, antenatal history, gestation and postcode of residence were collected. Clinical data including temperature, pulse rate, arterial pressure – invasive or noninvasive, capillary refill time, inotropic support and ventilation parameters at first look by retrieval team, at stabilisation and then on admission at receiving hospital, were collected. Discharge summaries from the tertiary hospital were obtained for outcome data.

Data were analysed utilising SPSS version 22.0 for windows. This study was approved by the Sydney West Area Health Service Human Research Ethics Committee – HREC 2007/8/4.13 (2652).

RESULTS

SUBJECTS

A convenience sample of fifty-five critically ill babies were studied from November 2007 to September 2011 and September 2012 to March 2015. A 12-month pause in the study resulted from the lead research neonatologist being unavailable for personal reasons. The median length of retrieval was 4 h:49 minutes (range: 2:53–13:45 hours), and the distance travelled to the patient's bedside was a median of 28.7 km (range: 1.4–469 km). The general median length of NETS retrievals is 5 hours 40 minutes (range: 0:33 minutes to 18 hours 16 minutes) (6). The median age at review by the NETS team was 4 hours:10 minutes (range: 47 minutes to 13 days). Thirty-six of the newborns were male. The median gestation of 53 term infants was 39 weeks (range: 37–41 weeks). Two critically ill, ventilated, preterm babies were included in this cohort one at 33 weeks who had TGA and one at 36 weeks with sepsis. The median birthweight was 3350 g (2220–5030 g). Six babies did not survive the neonatal period. The diagnoses of the neonates who were transported are outlined in Table 1.

Feasibility

There were challenges to conducting NUiT, so recruitment was slower than planned. The first was having a neonatologist with ultrasound skills available. This became easier when two consultant staff with CPU qualifications became available. The added weight of the scanner was seen as a barrier to flight planning, so both NUiT consultants added the GE Vivid*i* scanning kits' weight to their personal weights to simplify these calculations. Adding a third team member was occasionally a problem on fixed wing retrievals due to weight and seating restrictions. Unfortunately, we did not collect data on how often we were unable to attend an eligible retrieval, when we did attend however we were able to gain family consent and perform an ultrasound assessment. The problems in performing CPU whilst at the referring hospital were minor and included: finding an extra trolley to set-up the ultrasound laptop; performing the scan without interfering with the NETS teams stabilisation; and gaining adequate windows when scanning from unconventional positions from the head of the bed. The collection of ultrasound data on retrieval is feasible as useful data were collected on all retrievals.

Table 1 Diagnosis in retrieval

Diagnosis	No. (%)
Persistent pulmonary hypertension of the newborn (PPHN)	14 (25)
Hypoxic ischaemic encephalopathy (HIE)	13 (24)
Cyanotic heart disease	8 (15)
Meconium aspiration syndrome	6 (11)
Left heart obstruction	6 (11)
Infection	5 (9)
Other PCKD*, SGH#, collodion baby (ichthyosis lamellaris)	3 (5)
Total	55 (100)

*Polycystic kidney disease.
#Subgaleal haemorrhage.

Cardiac CPU findings

Circulatory compromise and management

Eleven (20%) babies had the evidence of haemodynamic compromise. Six babies had both low SVC (<50 mLs/kg/min) and low RVO (<150mL/kg/min). Low SVC flow was detected in nine babies – all with normal blood pressure. Low RVO was detected in eight babies of whom seven had normal blood pressure and one term baby had borderline low blood pressure – mean arterial pressure of 36 mmHg. In five babies where the studies remained observational (low flows noted but no intervention), the systemic blood flow remained low on admission to the receiving NICU. In the remaining six babies, the research consultants thought it in the best interests of the baby to suggest circulatory support management changes to the retrieval team in the form of fluid and inotropic support and subsequent improvement in systemic blood flow.

Diagnosis of structural cardiac abnormalities

On five occasions where there was a preretrieval clinical diagnosis of PPHN, CPU revealed cyanotic heart disease and the destination was changed from a tertiary perinatal hospital to a paediatric hospital with specialist cardiology services (Table 2). On three occasions where congenital cyanotic heart disease had been suspected, CPU suggested normal structure and all three infants were subsequently confirmed to have normal hearts; one at autopsy and two on echocardiogram at the agreed receiving destination perinatal hospital. On seven occasions, the cardiac CPU assisted in determining the right destination for the baby saving two transports and coveted children's hospital beds.

Cranial CPU findings

All babies had a cranial ultrasound in transport. In one baby, a subgaleal haemorrhage was documented – this was an incidental finding confirming clinical suspicion and is not part of routine cranial screening. Another instance of parietal and periventricular brightness on HUSS was later documented on MRI to be bilateral subacute (3–4 days old) occipito-parietal haematomas with evidence of diffuse oedema. The resistive index (RI) was documented with the median of 0.78 (normal = 0.51–1.0). RI value below 0.55 (measured in the anterior cerebral artery) correlates with a poor neurodevelopment prognosis, especially if measured in the first 24–72 hours after HIE (17–20). In those babies with a diagnosis of HIE, RI was measured at 0.61–0.77 with none below 0.55.

Miscellaneous CPU findings

One baby who presented with abdominal distention and severe pulmonary hypertension was noted to have large polycystic kidney disease on ultrasound and small volume lungs on chest radiograph. This baby's transport was redirected from a perinatal hospital to a children's hospital

Table 2 Diagnosis during NETS retrieval

Preretrieval clinical diagnosis	NUiT additional diagnosis	Paediatric cardiology diagnosis	Comments
PPHN	TGA/VSD	TGA/VSD	Destination changed
PPHN	Tetralogy	DORV with VSD	Destination changed
PPHN	TGA/VSD	TGA/VSD	Destination changed
PPHN	TGA/PFO	TGA/PFO	Destination changed
PPHN	TGA/PFO	TGA/PFO	Destination changed
Likely TGA with intact septum	TGA/PFO	TGA/PFO	Destination unchanged
Left heart obstruction	VSD/CoA – complex	TGA/VSD/CoA	Destination unchanged
Left heart obstruction	Normal structure/sepsis	Normal structure	Destination unchanged
Cyanotic heart disease	Structurally normal heart – PPHN	Structurally normal heart*	*Postmortem examination
Cyanotic heart disease	Structurally normal heart – PPHN	Structurally normal heart	Destination changed
Left heart obstruction	Interrupted aortic arch	Fenestrated PFO/ASD, lge conoventricular VSD. AV and asc aorta small, interrupted ao arch type B.	Needed CT angiogram to delineate anatomy
Acyanotic heart disease	VSD/bicuspid AV	VSD/bicuspid AV/CoA	Destination unchanged
Left heart obstruction	CoA with poor contractility	CoA with biventricular failure	Inotropes added in retrieval
Cyanotic heart disease	Tetralogy, no PDA seen	Absent PV syndrome	Died day 5
Coarctation of aorta	CoA with poor contractility No PDA	CoA with poor contractility No PDA	Retrieval into theatre expedited
Coarctation of aorta	CoA with acceptable cardiac function	CoA with acceptable cardiac function	Destination unchanged

PPHN, persistent pulmonary hypertension of the newborn; TGA, transposition of the great arteries; VSD, ventricular septal defect; CoA, coarctation of the aorta; PFO, patent foramen ovale; PDA, patent ductus arteriosus.

where autosomal recessive polycystic kidney disease was confirmed and the baby died. One baby with critical coarctation of the aorta remained unwell on maximal prostaglandin E1 infusion and was shown to have a ductus arteriosus that remained closed. Transport was expedited to the cardiac centre where the findings were confirmed by a paediatric cardiologist and transfer to the operating theatre for surgical repair was expedited. The baby survived.

DISCUSSION

This is the first study to explore the benefits and feasibility of CPU in the transport of critically unwell neonates. We have shown that ultrasound assessment can be reliably utilised to guide management on retrieval without prolonging the retrieval times (7). The advent of the laptop sized ultrasound machine has meant it is feasible to have access to ultrasound assessment on neonatal transport. The main challenge to using this technology in retrieval is having clinicians skilled in ultrasound who are available for transports. Since starting this research study, the development of a training and accreditation programme for neonatal CPU in Australia and New Zealand (5) has evolved to the point where most Australasian neonatal trainees are now graduating with ultrasound skills. This expansion of ultrasound skills is being mirrored internationally. So, although skill availability remains a significant impediment, the feasibility of including ultrasound assessment on more transports is increasing (21–23). Ultrasound equipment is also becoming smaller as technology evolves and although compact, the machine used in this study was relatively bulky and its weight had implications for air transport. There are now tablet sized ultrasound machines even more suited to retrieval available on the market.

From previous research, we know that blood pressure and other clinical signs are inaccurate markers for cardiac output in newborn babies who are in circulatory transition (24). The NUiT study revealed that critically ill transported neonates have a high risk of haemodynamic pathology that may not be clinically apparent with 11 (20%) babies having ultrasound evidence of haemodynamic compromise but with normal blood pressure.

One of the major advantages shown by this study was the ability to triage a baby to a more appropriate receiving hospital. On average, NETS transports ten babies each year for a second time because cardiac disease was undetected on the first transport (7,25). These babies may suffer barotrauma and pneumothorax as referring teams attempt to improve oxygenation with inappropriate high-pressure ventilation (7,26). Six of the 55 babies (11%) in this study had their receiving hospital changed from a perinatal hospital to a children's hospital on the basis of the CPU findings at the referral hospital, and three (5%) who were clinically suspected to have CHD were found to have structurally normal screening CPU scans. One died at the referring hospital, and two had normal structure confirmed at the perinatal centres. Five had clinically unsuspected CHD, and the one baby had undiagnosed polycystic renal disease. Notwithstanding the clinical advantage of early access to the specialised skill mix that these babies needed, there were significant cost savings in avoiding a second transport (27). The average cost for an air ambulance

transport is €3220, for road ambulance is €777 and for helicopter transport is €5732 (7). From a previous audit, it is known that NETS transports eight babies per year with transposition of the great arteries that are born off campus of a paediatric cardiology centre many requiring a second transport (25).

Cerebral ultrasound added limited information in this age group of babies. In the baby with subgaleal haemorrhage, CPU confirmed an obvious clinical diagnosis and assisted haemodynamic management (28).

This study involved including a neonatologist on retrieval which added to the team's capacity to be able to counsel the families. Consent for ultrasound was gained from families by explaining the observational nature of the study, the skills and limitations of the neonatologist scanning and the need to refer when abnormal cardiac structure was identified. No diagnosis was given until confirmed by a paediatric cardiologist.

Our plan for the future, in the light of these findings, is to facilitate the use of ultrasound assessment into the NETS clinical service with the acquisition of more portable equipment such as the newer tablet based ultrasound machines. We also aim to increase staff training in point-of-care ultrasound and CPU. We are developing a protocol that will allow targeting of retrievals where access to ultrasound will be of most benefit. This will include those babies who are ventilated with presumed hypoxic respiratory failure, hypoxic ischaemic encephalopathy, sepsis or hydropic infants.

CONCLUSION

The NUiT study has shown that CPU in neonatal transport is feasible and allows more accurate triage of possible cardiac babies to an appropriate receiving hospital. NUiT has also demonstrated the complexity of haemodynamics in critically ill term and near term newborns in transport and that compromise is not always recognised using clinical assessment. Adding ultrasound to the haemodynamic assessment may allow for a more individualised and targeted approach to management.

The generalisability of these findings will improve as more neonatal clinicians are trained in point-of-care ultrasound and ultrasound equipment becomes more portable.

COMPETING INTERESTS

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