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REGULAR ARTICLE

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

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ABSTRACT

Aim: Document the incidence of haemodynamic pathology in critically ill preterm newborns requiring transport.

Method: A transport neonatologist performed cardiac and cerebral ultrasound before and after transportation of infants born ≤30 weeks gestation.

Results: Forty-four newborns were studied in 2008–2015; of them, 21 were transported by road, 19, by helicopter and four, by fixed wing: median birthweight, 1130 g (680–1960 g) and median gestation, 27 weeks (23–30); 30 of 44 were male babies. Antenatal steroid course was complete in two babies. Ultrasound in the referring hospital was at a mean of two hours: 47 minutes (00:15–7:00) of age. Low systemic blood flow was common: 50% had right ventricular output <150mL/kg/min and 23%, a superior vena cava flow <50mL/kg/min. at stabilisation. Cranial US: 10 Grade I IVH, 2 Grade II IVH, 1 Grade IV IVH and 32 normal scans pretransport. After transport, three further Grade I IVH were reported. Mortality was higher in the babies with low systemic blood flow: 4 of 12 (33%) died vs 1 of 31 (6%) in the normal flow group (OR = 7.2, 95% CI: 1.1 to 47, p = 0.022).

Conclusion: Point-of-care ultrasound during the retrieval of preterm infants confirms a high incidence of haemodynamic pathology. The use of ultrasound during transport may provide an opportunity for earlier targeted circulatory 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 (1–5).

Some of the highest risk preterm 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 of haemodynamic and cerebral pathology when assessed with ultrasound on arrival at the tertiary NICU (6).

Abbreviations

CPU, Clinician performed ultrasound; NETS, Neonatal Emergency Transport Service; NUiT, Neonatal Ultrasound in Transport; SVC, Superior Vena Cava; RVO, Right Ventricular Output; PDA, Persistent Ductus Arteriosus; ELBW, Extremely Low Birthweight; IVH, Intraventricular Haemorrhage; NICU, Neonatal Intensive Care Unit; GE, General Electric.

Ultrasound machines are now portable, making it possible to 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 firstly to describe the feasibility of the use of point-of-care ultrasound during neonatal transport, secondly, to determine the incidence and nature of

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 extremely preterm newborn, adds to the diagnostic capabilities and facilitates targeting of therapy.
- Ultrasound can be integrated into the assessment of the critically ill newborns requiring retrieval to tertiary care.

haemodynamic problems in a cohort of very preterm newborns requiring early postnatal transfer to an NICU and, thirdly, to document the effect of transport on the rate of IVH in this very vulnerable group. A parallel study of babies born after 34 weeks has been described in a separate paper (7).

METHODS

This was a prospective observational cohort study performed by the Newborn and paediatric Emergency Transport Service (NETS) (6), which serves 254 hospitals in New South Wales, Australia, 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 (8). 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 including 80 transfers of babies born before 30 weeks of gestation (6). Babies who need higher level intensive care are transferred to one of the nine tertiary hospitals. Regional and metropolitan referring hospitals in Australia have special care nurseries run by general 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 – Neonatal (9) (KC or TL from 2012 or MG from 2014) accompanied the transport team with ultrasound equipment. Babies were eligible if they were born at or before 30 weeks of gestation, an ultrasound-trained retrieval neonatologist was available and mode of transport did not preclude 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, that is after ultrasound recognition of unsuspected major congenital heart disease or evidence of significant haemodynamic compromise.

Ultrasound protocol

On arrival at the referring hospital, parental consent was obtained to perform the studies utilising the GE Vividi® laptop ultrasound scanner (10). Ultrasound studies were conducted following the stabilisation of the patient by the NETS team at the referring hospital and, when feasible, following the 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.

Cardiac ultrasound studies

Assessment of 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) and persistence of the ductus arteriosus (PDA) were documented using referenced methodology (11–15). The measures of systemic blood flow (SVC flow and RVO) have been correlated with adverse outcomes in neonates (16,17).

Cerebral ultrasound studies

Sagittal views of right and left ventricles and a coronal sweep, were performed.

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, inotropic support and ventilation parameters at first look by retrieval team, at stabilisation and then on admission at the receiving hospital were collected. Discharge summaries from the tertiary hospital were obtained for outcome data.

Data were analysed utilising SPSS version 23.0 for Windows (IBM Corporation, Armonk, NY, USA). 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 44 newborns was studied between November 2007 to September 2011 and September 2012 to June 2015. There was a 12-month pause in the study due to the unavailability of the research neonatologist.

Eleven babies who were twins were followed up – five sets of twins and one of twins (the other not recruited to study). Twenty-one babies were transported by road ambulance, 19 by helicopter and four by fixed wing transport. The median distance travelled to the patient's bedside was 71.8 km (range 0.3–466 km). The mode of delivery was cephalic vaginal for 19 babies, breech vaginal for four babies and via caesarean section for 21 babies. Median birthweight was 1130 g (range: 680–1960 g) including 14 under 1000 g. The median gestation was 27 weeks (23–30), and 30 were male babies. Antenatal steroids were complete in two babies and incomplete in eight babies, and 32 babies had none. Ultrasound in the referring hospital was attended at a mean of two hours : 47 minutes (range 00:15–7:00) of postnatal life. As a marker of general preterm newborn care, thermal control was reviewed. Fifteen of 44 had a recorded temperature of less than 36°C at first look by the NETS team, 4 of 44 at stabilisation by the NETS team and 3 of 44 on tertiary admission. See Table 1 for observed baseline clinical variables by retrieval team at first look.

Table 1 Baseline clinical variables at first look by retrieving team

Parameter	Median	Range
Temperature °C (F)	36.4 (97.52)	33.2–37.6 (91.76–99.68)
Respiratory rate bpm	57	32–72
Heart rate bpm	159	80–197
Oxygen saturation %	94	34–100
Mean arterial blood pressure (mmHg)	32	22–57

Feasibility

There were challenges to conducting NUiT, so recruitment was slower than planned. The first was having a skilled sonographer available. This became easier when three consultant staff with CPU qualifications became available. The added weight of the scanner was seen as a barrier to transportation through flight, so the NUiT consultants added the GE Vivid*i* scanning kits' weight to their personal weights to ease it. 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. However when we did attend, we were able to gain family consent and perform an ultrasound assessment. The problems in performing CPU at the referring hospital were minor and included the following: 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. During stabilisation of these preterm infants, it was often most convenient to scan postintubation and surfactant replacement therapy whilst awaiting steady state of ventilation requirements for pretransport blood gas analysis. It took ≤15 minutes for scanning to complete. The collection of ultrasound data on retrieval is feasible as useful data were collected on all retrievals.

Cardiac CPU findings

The SVC flow in 43 babies through ultrasound was documented following the NETS team stabilisation in the retrieval hospital – one was missing because of machine malfunction early in the study period. Forty-two babies had an RVO flow recorded at stabilisation – the same one was missing due to machine malfunction, and the other had only SVC flow and HUSS recorded as scanner and neonatologist arrived late to the retrieval.

Twenty-one of 42 babies (50%) had an RVO less than 150 mL/kg/min, and 12 of 43 (23%) had an SVC flow less than 50 mL/kg/min. In total, 27 of 44 (61%) babies in this cohort had evidence of low systemic blood flow (either low SVC or low RVO, or both) in retrieval. Eight babies were recorded as having both low SVC and RVO flow. In Table 2, these eight have their clinical observations and metabolic data shown with simultaneous RVO and SVC flows.

On arrival into the tertiary NICU, 31 babies had a repeat scan. Not all babies received a repeat scan as the scanning neonatologist was not always able to travel with the NETS team.

Twelve babies with low systemic flow at stabilisation had a repeat scan on admission, and eight of those babies had evidence of persistently low systemic blood flow on admission (see Fig. 1).

The ductus arteriosus was assessed in 43 babies, and all had a demonstrable PDA with a median size of 2.8 mm (1–4.2 mm), but none were closed. Assessment of ductal flow pattern showed 13 with left-to-right flow, 26 were bidirectional and 4 were right to left.

In the normal SVC flow babies, 1 of 31 (6%) died within 72 hours of birth. In the low SVC flow babies, 4 of 12 (33%) died (OR = 7.2, 95% CI: 1.1 to 47, p = 0.022).

Twelve babies recorded a mean blood pressure in retrieval that was less than or equal to the 10th percentile. Of those babies with a mean BP greater than the 10th percentile for gestational age, 19% had low SVC flow, and of those with mean BP less than or equal to the 10th

Table 2 Observations and metabolic status at time of NUiT and low systemic blood flow

Case No.	GA	Axillary temperature	HR	MBP	CRT	pH	Lactate	SVC flow	RVO flow	Comments/HUSS
1	25	37	176	44	<two seconds	7.34	NA	34	49	Grade IV IVH*
2	29	35.5	150	27	<two seconds	7.21	3.7	41	92	HUSS normal
3	26	33.2	144	29	<two seconds	7.27	4.9	39	91	HUSS normal
4	26	33.3	114	28	<two seconds	7.6	5.8	29	108	HUSS normal
5	25	36.7	141	18	Four seconds	7.21	12.5	NA	79	Decreased filling of heart HUSS normal*
6	28	35.3	135	27	<two seconds	7.18	NA	43	133	HUSS normal
7	25	37	168	27	Four seconds	6.97	NA	10	104	HUSS normal*
8	29	36.4	162	54	<two seconds	6.58	20	NA	36	Inotropes targeted so flow was visible on admission HUSS normal

GA = completed weeks of gestation at birth; 28; HR = heart rate beats per minutes; MAP = mean arterial pressure mmHg; CRT = capillary refill time; SVC = superior vena cava in mL/kg/min; RVO = right ventricular output in mL/kg/min. NA = not available; HUSS = head ultrasound scan.
*Death within 72 hours of birth.

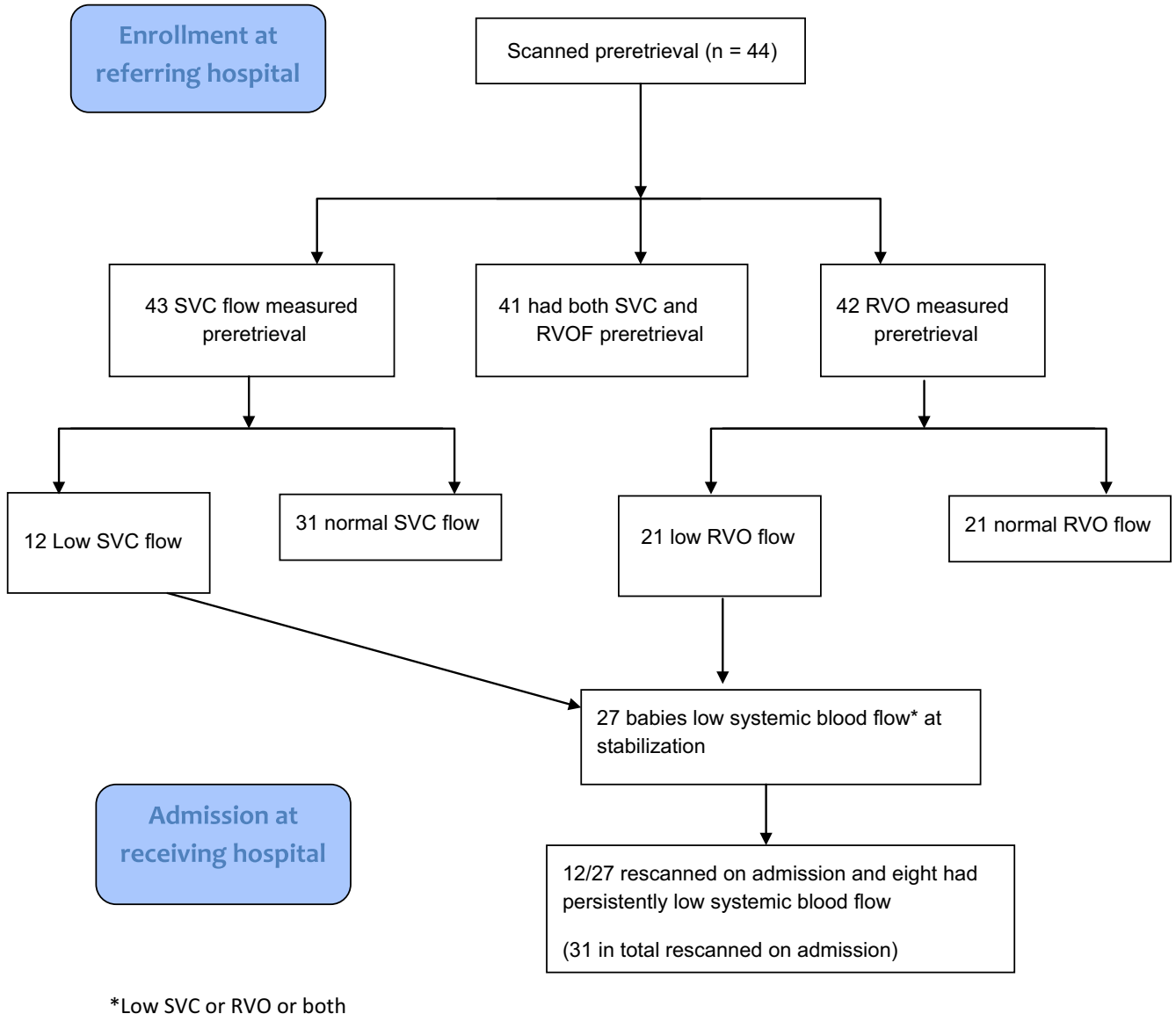

Figure 1 Flow of babies scanned pre- and postretrieval.

percentile for age, 54% had low flow (OR 0.19, 95% CI: 0.044–0.85, p = 0.022).

In four babies, the studies remained observational (the flows were low but not calculated in retrieval and therefore not intervened) and these flows remained low on admission to the receiving NICU. In ten babies, the SVC and RVO flows were so low that the NUiT study consultants thought it in the best interests of the baby to suggest the addition of dobutamine infusion and the flows were improved on arrival in the NICU in nine of these babies. One baby in which dobutamine was added in view of low SVC and low RVO flow had much worse flows on arrival into the NICU. In one baby born hypovolaemic following antepartum haemorrhage, the flows and the blood pressure remained low despite crystalloid and blood products, dobutamine, dopamine and hydrocortisone treatment of blood pressure. This baby died.

No babies in this preterm cohort were found to have congenital heart disease with CPU in transport. One baby, born at 28 weeks of gestation, developed coarctation of the aorta on day eight of postnatal life in the NICU. On review of the transport ultrasound with a paediatric cardiologist, there was no evidence of coarctation on the retrieval scans.

Cranial CPU findings

Cranial USS revealed 10 Grade I IVH, 2 Grade II IVH, 1 Grade IV IVH and 32 normal scans pretransport. After transport, the NUiT study consultants repeated the scans and found no change in the cranial scans. However, three further Grade I IVH were recorded following the

radiologist review and report of post-transport scans attended by the clinical team. There was no later progression of any of the IVH that were apparent on pretransport ultrasound.

In three babies, counselling was enhanced by the knowledge of the head ultrasound findings. One baby at first look by the NETS team had a Grade IV intraventricular haemorrhage, one extremely unwell 25-week baby had a normal preterm head ultrasound, and one well 23-week baby had a normal preterm head ultrasound.

DISCUSSION

To the best of our knowledge, this is the first study to explore the benefits and feasibility of point-of-care ultrasound in the transport of very preterm neonates. The advent of the laptop-sized ultrasound machine has meant it is feasible to have an access to ultrasound assessment during neonatal transport. The greatest challenge to using this technology in retrieval is having clinicians skilled in ultrasound who are available for transports. Recruitment to this study was initially prolonged due to the urgency of the transports and the availability of an on-site qualified neonatologist. A training and accreditation programme for neonatal CPU in Australia and New Zealand (9) 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 improving (18–20). Ultrasound equipment is also becoming smaller as technology evolves. Although compact, the machine used in this study was relatively large and its weight had implications when transported via aircraft. There are now tablet-sized ultrasound machines on the market, even more suited to the retrieval environment.

Blood pressure and other clinical signs are unreliable markers for cardiac output in newborn babies who are in circulatory transition (21) and in a transport cohort are unlikely to have had the benefit of antenatal steroids. This study has revealed that transported preterm neonates have a high risk of haemodynamic pathology that will often not be clinically apparent. More than 60% of babies had ultrasound evidence of haemodynamic compromise. In this convenience sample, we found that the odds of having low SVC flow were reduced by 80% in those with normal BP relative to those with low BP; however, the direct correlation with BP was unrelated. As demonstrated in Table 2, the ultrasound studies added to the clinical information already available, which may or may not provide complete physiological information. Whilst acknowledging the intra-observer variability of measurements with CPU is approximately 10% and interobserver is in the range 15–20% (15), the addition of the cardiac output information enable us to influence the choice and addition of fluids and inotrope to the clinical scenario to at least the short-term advantage of nine babies.

Previous studies have shown that the duration of low SVC flow may impact long-term neurodevelopmental outcome, so shortening this time period may be clinically important (16,17).

This study was *a priori* designed to be observational, so the scans were planned to be recorded in transport and interpretation deferred until the postretrieval period. Where this was strictly adhered to, four babies did not receive the added benefit of inotropic support in retrieval and still had low flows on admission to the tertiary NICU.

Cerebral ultrasound added valuable information in this age group of babies, and it is reassuring to those of us working in neonatal transport that it did not appear that the transport process contributed to deterioration in the cranial ultrasound findings. None of these babies had an extension of the IVH immediately post retrieval on admission to the NICU. This is despite significant vibration forces in the different modes of transport particularly the rotary wing and road vehicles. This information adds detail to the previous reports where interfacility transport revealed increased rates of IVH (22,23). Our data would suggest that it is the vulnerability of the cohort of premature infants that are outborn and not the actual transport process that put them at greater risk of IVH. This is consistent with a study by Watson et al. (2013) who also demonstrated that although very low-birthweight infants transported during the first two days of life have higher rates of IVH than infants born at a tertiary care facility, this relationship may be explained by associations with underlying clinical variables rather than transport itself (24). Our rate of high-grade IVH being only 2% is much lower than that in the previous reports (24,25). This may be related to our low numbers and random sample of convenience.

Being cognisant of the head ultrasound findings allows for more informed counselling in retrieval. The occasion where the baby had evidence in retrieval of Grade IV unilateral IVH did not change the course of the retrieval; however, it did allow for preparation of the parents of an outcome that would include a severe disability if not death. In a recent review of 1472 newborns 23–28 weeks in NSW, infants with grade III-IV intraventricular haemorrhage (IVH; n = 93) had higher rates of developmental delay (17.5%), cerebral palsy (30%), deafness (8.6%) and blindness (2.2%) (25).

The mortality rate in our study group was more favourable, 11% (NUiT) vs 25% shown in the previous studies (23,24). The hypothermia rates of 6% on admission are within international benchmarking standards (26). This may be attributed to the high degree of specialisation of both medical and nursing staff particularly with regard to thermal management of the ELBW baby and a great degree of centralisation, preventing dilution of resources and clinical commitment in NSW and ACT (27).

Our plan for the future, in the light of the findings of this study, is to integrate ultrasound assessment into the NETS clinical service with the acquisition of even more portable equipment and staff training in point-of-care ultrasound and CPU. With further formalising of the cardiac output

studies and the head ultrasound scans, we should in the future be able to report more consistent data on the pre- and post-transport condition of this vulnerable group of babies and further focus the improvement in their care and the stability of their transport.

CONCLUSION

This NUiT study has shown that CPU in neonatal transport is feasible. It allows more accurate triage of haemodynamic status and targeting of inotropic support. It has also demonstrated the complexity of haemodynamics in critically ill preterm newborns in transport and suggests the need for individualised 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

The authors have no competing interests to declare.

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