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RESEARCH

The utility of point-of-care ultrasound protocol to confirm central venous catheter placement in the preterm infant

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Abstract

Central vascular access is frequently required for preterm infants. Confirmation of positioning of central line is typically on chest and abdominal radiographs; POCUS is a relatively novel diagnostic method. Misdiagnosis is the main concern limiting use of this modality. The aim of this study is to validate our standard protocol accuracy in locating the central catheter position by correlating catheter position as determined by POCUS with radiographs. Premature babies < or equal to 30 weeks gestation who had peripheral central lines or surgical lines were enrolled. Confirmation of line position by radiographs was compared to images obtained through a specific US protocol technique. The operator of US exam was blinded to the radiograph findings. All images were reviewed by two radiologists who were blinded to the radiograph findings. 35 central line placements were assessed. 22 lines were inserted in the UL, and 13 were inserted in the LL with a total of 91 ultrasound scans and radiographs. The position of the line was interpreted as normal in 79/91 scans with interpreter reliability of κ=0.778 (p < 0.001), sensitivity of 0.83 and specificity of 0.96, and positive predictive value of 0.77 and negative predictive value of 0.97. There was no significant difference between the ultrasound interpretation and the radiograph interpretation of UL and LL.

Conclusion: The protocol of POCUS that we propose is a reliable tool for assessing the central line positions in preterm infants.

What is Known:
• *POCUS is a reliable tool assessing the central line positions in preterm infants.*
What is New:
• *The protocol of POCUS that we propose is a reliable tool for assessing the central line positions in preterm infants.*

Keywords Central line position · POCUS · Preterm infants

Abbreviations

UL	Upper limb
LL	Lower limb
US	Ultrasound
PICC	Peripherally inserted central catheter
CVC	Central venous catheter
CXR	Chest X-ray
RA	Right atrium
IVC	Inferior vena cava

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SVC	Superior vena cava
SC	Subclavian vein
INV	Innominate vein
CVL	Central venous line
NICU	Neonatal care unit
GA	Gestational age
POCUS	Point of care ultrasound

Introduction

Central vascular access is required frequently for preterm infants admitted to the neonatal intensive care unit (NICU). The central vascular access allows for the infusion of higher concentrations of fluids and total parenteral nutrition and obviates the need for frequent insertion of peripheral intravenous catheters [1]. The trend towards resuscitation and survival of younger preterm newborns and treatment of infants with more complex congenital anomalies has resulted in more infants requiring central venous lines for longer durations.

Catheter tip malposition is a common complication even in an era of ultrasound-guided CVC/PICC insertion [2].

The current reference standard for confirmation of the correct central line insertion is an anteroposterior chest radiograph for the lines inserted through the upper limbs (UL) and chest and abdominal radiograph for the lines inserted through the lower limbs (LL) [3]. Multiple studies confirmed the effectiveness of ultrasound (US) exams in confirmation of central line position in settings of NICU [4–8].

Barriers to the routine use of US of central lines in NICU and in particular of point of care ultrasound (POCUS) include the risk of misdiagnosis, liability concerns and the lack of outcome-based evidence. Sufficient POCUS practice depends on close collaboration with the consultative specialties and standardized training and accreditation for neonatologists using ultrasound [9].

Our goal is to validate our standard protocol accuracy in locating the tip of the central catheter position by correlating US of central lines with radiographs.

Methods

The study was conducted from March 2017 to August 2018 in 2 tertiary NICUs of Winnipeg, Manitoba, Canada. The institutional ethics board approval was obtained for prospective study and reviewed by the Biochemical Research Ethics Board Premature babies less than or equal to 30 weeks who had PICC lines or surgically inserted central lines were eligible. Informed consent was obtained from their parents. Infants ≥ 40 weeks postmenstrual age and infants with congenital anomalies which could affect the imaging findings were excluded. Infants who had umbilical lines placements were not eligible.

POCUS were obtained by a neonatology fellow with 3-year experience in neonatal US and echocardiography. POCUS was performed after each chest radiographs obtained for confirmation of the line position. The chest radiographs were reviewed and reported by pediatric radiologists. The ultrasound operator was blinded to the results of line positioning identified on chest radiography.

The ultrasound images were performed utilizing Zonare-M6® (ZONARE Medical Systems, USA—California), with C6-12 microconvex probe. All images were obtained using grayscale as 2D and color Doppler to confirm the intravascular position of the central line. The images were interpreted by the neonatology fellow (the operator). In addition, the images were interpreted by two pediatric radiologists (11 and 20 years of experience) who were blinded to the results of chest radiographs and to the operator's interpretation of US results. The differences in interpretation were solved in consensus. The results of interpretation were compared to the radiograph reports.

POCUS protocol for lower limb central lines

1. The ultrasound exam starts with the probe positioned obliquely over the middle part of the chest between the 2 nipples (short parasternal view) (Fig. 1). This is to check if the line is visible inside the right atrium (RA) or at the junction between the RA and the inferior vena cava (IVC).
2. If the line is not visualized, the probe is repositioned along the midline of the upper abdomen (subcostal sagittal view) in order to explore the upper IVC (Fig. 2a)
3. If the line is not visualized in upper IVC, the probe is repositioned inferiorly (Fig. 2b) to visualize the lower part of the IVC.

POCUS protocol for upper limb central lines

1. The ultrasound exam starts with the probe positioned obliquely over the upper chest (short parasternal view) (Fig. 1). This is to visualize the line within the RA or at the junction between the RA and the superior vena cava (SVC).
2. If the line is not visualized inside the RA or at the junction between the RA and the SVC the probe is repositioned obliquely over the left upper chest with the nob directed to the left shoulder (Fig. 3a). This is to identify the left innominate vein (left INV), which is situated just above the aortic arch.
3. If the line is not visualized within the left INV (Fig. 3a) the angle of the probe is rotated to the right (Fig. 3b) in order to visualize the left INV joining the right INV to form the SVC.

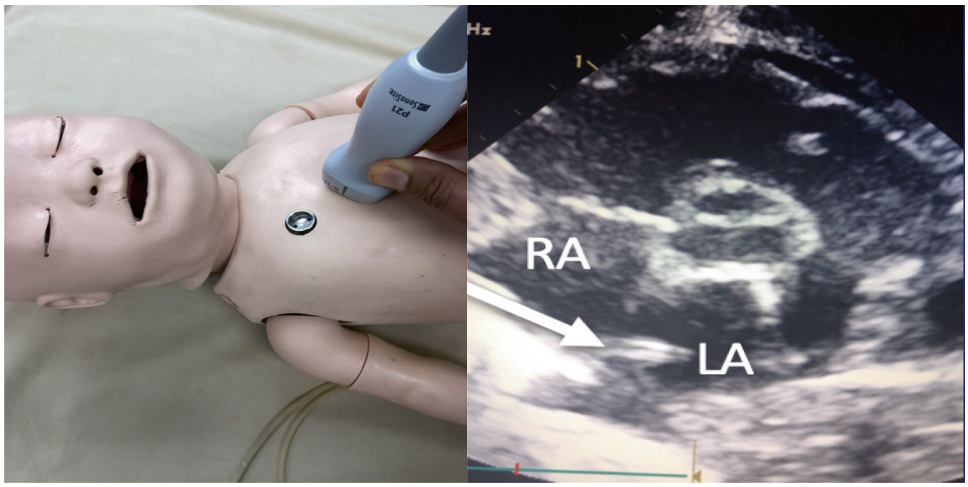

Fig. 1 The probe positioned obliquely over the middle part of the chest between the 2 nipples (short parasternal view). If the tip of the line is visualized within the RA, the line is considered mispositioned, and no further US imaging is required. In this image, the line (arrow) is crossing the foramen ovale and entering the RA

4. If the line is not visualized, the probe is repositioned more laterally to Fig. 3a in left upper limb central lines, the probe is positioned towards the left shoulder (Fig. 3c) to visualize the left subclavian vein (SC).
5. If the line was inserted in the right upper limb, the probe will be positioned towards the right upper chest/right shoulder (Fig. 3d) to visualize right INV and the right SV.

If the line is visualized in the RA, the position is considered abnormal. If the US failed to visualize the line, the exam should be considered nondiagnostic.

PICC lines are mobile and move when arm position changes. In our study, we followed the standard resting position of the upper extremities in both imaging techniques, which is the arm adducted at approximately 30–45 degrees

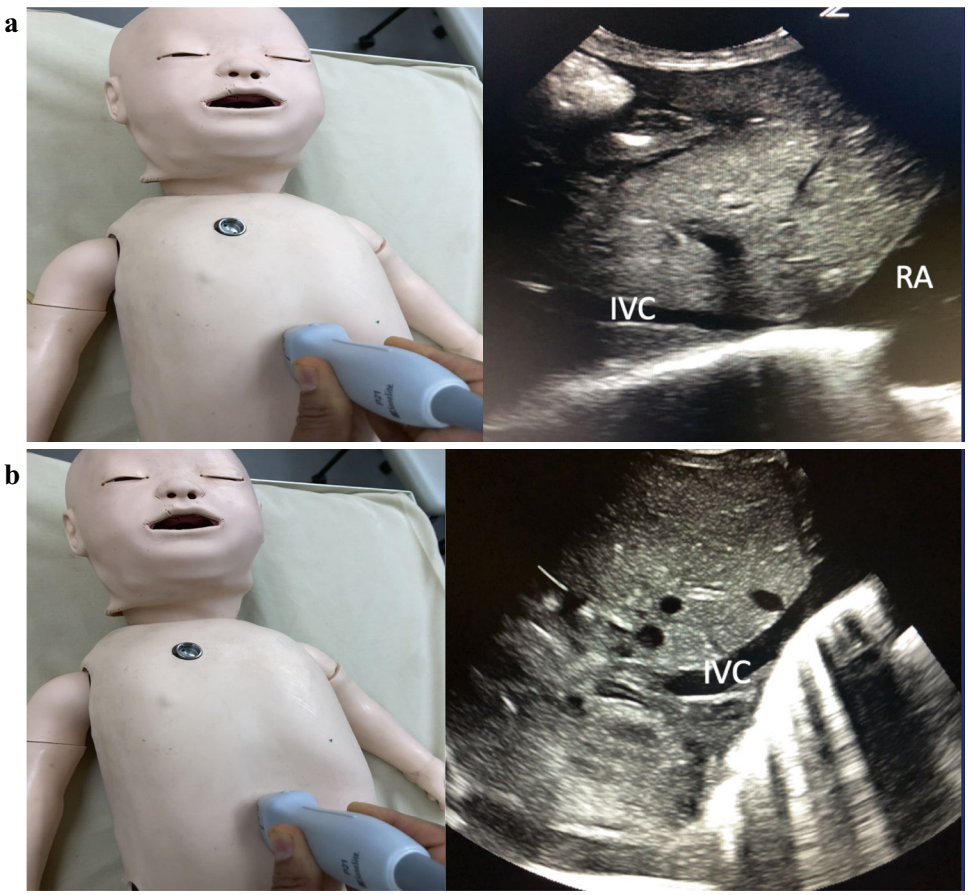

Fig. 2 **a** The probe is repositioned along the midline of the upper abdomen (subcostal sagittal view). **b** The probe is repositioned inferior to the subcostal sagittal view to visualize the lower part of the IVC

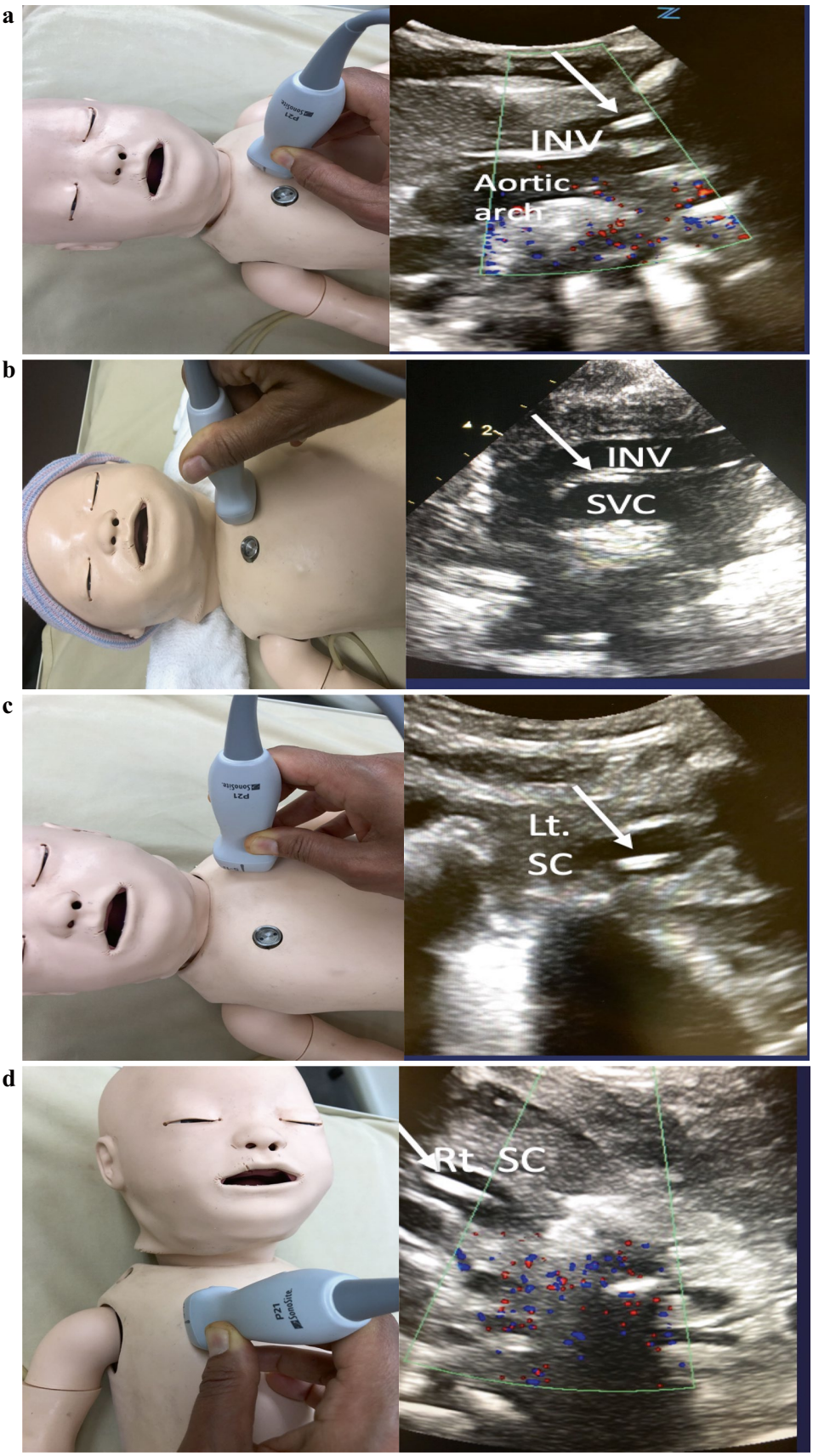

Fig. 3 **a** The probe is positioned obliquely over the left upper chest with the nob directed to the left shoulder to identify the left innominate vein (left INV), which is situated just above the aortic arch. **b** The angle of the probe is rotated to the right of the position shown in (**a**) in order to visualize the left INV joining the right INV to form the SVC. If the tip of the line is visualized within the innominate vein, SVC, or cave-atrial junction, the line is considered normally positioned, and no further US imaging is required. **c** The probe is repositioned more laterally to (**b**). If the line was inserted in the left upper limb, the probe is positioned towards the left shoulder to visualize the left subclavian vein (SC). **d** The probe is positioned towards the right upper chest/right shoulder to visualize right INV and the right SV if the line is inserted in the right upper limb. If the tip of the line is not visualized in the innominate vein, SVC or cake-atrial junction the subclavian veins should be evaluated

Table 1 The demographic characteristics of the study population

N **= 31**		
Gestational age (weeks)	Mean = 26.13	SD 2.08
Birth weight (grams)	Mean = 930	SD 246.5
Antenatal steroids (%)	*n* = 25	% 80.6
Vaginal delivery (%)	*n* = 14	% 45.2
Sepsis (%)	*n* = 20	% 64.5
Necrotizing enterocolitis (NEC) %	*n* = 5	%16.1
Chronic lung disease (CLD)	*n* = 2	% 7.7
Retinopathy of prematurity (ROP) %	*n* = 5	%18.5
Intraventricular hemorrhage (IVH) %	*n* = 11	% 35.5
Periventricular leukomalacia (PVL) %	*n* = 4	% 12.9
Death %	*n* = 5	% 16.1

to the body. For identifying the position of the lower limb catheters, the legs were kept in the "froglike" position.

Statistics

Durations of chest radiography and the US exams have been summarized using means and standard deviations. Durations were compared between procedures using a linear mixed-effects model including both procedures (chest radiographs vs. ultrasound) and the location (UL vs. LL), while accounting for the paired nature of the procedure's duration measurements. Inter-rater reliability among ultrasound interpreters has been summarized using Fleiss' Kappa for raters, and the interpretation of the ultrasound findings compared to the standard of care chest radiograph interpretation has been summarized using sensitivity and specificity, with 95% confidence intervals.

Results

A total of 33 premature infants less than 30 weeks gestation were enrolled with a total of 35 central lines inserted. Two infants had more than 1 line placement. Twenty two lines were inserted in the UL, and 13 were inserted in the LL. A total of 91 scans were performed with 44 assessing the UL and 47 assessing the LL.

The demographic characteristics of the study population are shown in Table 1.

The position of the line was interpreted as normal in 79 scans (86.8%) and abnormal in 12 scans (13.2%). The interpreter reliability for the ultrasound interpreters was found to be κ=0.778 ($p < 0.001$).

The comparison of POCUS to chest radiographs interpretations has been summarized. The estimated sensitivity of POCUS was 83% (95% CI: 52–98%), the specificity was 96% (95% CI: 89–99%), the positive predictive value was 77% (95% CI: 46–95%), and the negative predictive value was 97% (95% CI: 91–100%). There was no significant difference between the POCUS interpretation and the chest radiograph interpretations in UL versus LL.

The chest radiographs took 4.07 s longer than POCUS ($p < 0.001$; 95% CI: 3.53–4.61). The ultrasound of upper limbs took 0.93 min longer on average than ultrasound of lower limbs ($p = 0.001$; 95% CI: 0.38–1.48). We found that the average change in catheter position (the migration of the catheter tip) between the exams was 2.2 rib spaces (as little as 0.5 rib spaces and up to 3.5 rib spaces). The shortest position is that at the time of insertion, i.e., arm abducted 90°, elbow straight.

Discussion

In our study, US demonstrates sensitivity of 83% and specificity of 96% in evaluation of central line tip position in relation to chest radiographs as a reference standard.

In a recent systematic review of diagnostic accuracy of US for localizing PICC lines in NICU, the authors reported the pooled sensitivity value of 97.4% and pooled specificity value of 91.4% [10]; however, in two of the reviewed studies, the results were altered by inaccurate interpretation of radiographs, which caused significantly lower values of sensitivity and specificity [11, 12]. These studies have not been included to the meta-analysis.

There is a growing concern about accuracy of chest radiographs as a reference standard for assessment of central line position in both adult and pediatric patients and particularly in neonates [8, 13].

The researchers noticed large inter-observer variability among radiologists in identifying the cavoatrial junction on radiographs; therefore, a radiograph alone may not be sufficiently accurate to identify intra-atrial tip position [14, 15]. One-dimensional and static aspect of radiographs makes the confirmation of line position imprecise as it shows the anatomical landmarks but does not prove that the line is positioned within the vessel's lumen. Multiple radiographic views can better define the position of central lines but result in greater cumulative exposure to ionizing radiation in preterms. Central venous lines placement accounted for 22% of radiation exposure that exceeded the recommended maximum in premature infant [13, 16].

In our study the interpreter reliability for the POCUS interpreters was statistically significant ($p < 0.001$). There was no significant difference between the POCUS interpretation and the radiographic interpretation in both upper and lower limbs.

There are a variety of protocols suggested for US of central lines in NICU [4, 6, 8]. In our protocol, the US exam starts from the view of the right atrium for both UL and LL

central lines rather than from SVC or IVC views. It allows to confirm or exclude malposition (deep position) of the tip of the line in the first moments of the exam, preventing unnecessary further examination.

In our study, the time spent for obtaining the POCUS was only slightly shorter when compared to time of radiographs (approximately 4 s) while other authors reported that the time period taken for US exam was significantly shorter than that of radiograph [4, 7, 8, 12]. That may be explained by operator-dependent character of exam and lack of regular practice. The timing required for US exam may decrease as the operator gains more expertise.

The advantages of US of central lines in preterm patients include real-time assessment of the tip position, absence of radiation exposure, minimal handling of the neonate, easy identification of central line migration, and the possibility of subsequent repositioning of the central line under US guidance [7, 17–19]. Recently, the American Academy of Pediatrics recommended to use POCUS as the standard of care to assess central line placement and position [20]. A larger study done in 2021 proved the feasibility of POCUS to locate the catheter tip they looked into upper limb 118 PICCS with a total agreement of 88 of 109 ultrasounds compared to radiographs [21].

One of the main known limitations of US exam is its operator dependence, which may result in inaccurate interpretation of the images. In our study, one operator performed all the scans which could be considered a limitation. On the other hand, a single operator guaranteed high compliance of our study protocol. Further studies with multiple operators may better evaluate the utility of our proposed protocol. The implementation of bedside ultrasound of central lines in NICU is limited by lack of guidelines, unified protocols, and lack of standardized training of the operators. The detailed protocol of POCUS that we propose is aimed at better delineating the position of central lines and helping to establish US as a reliable imaging tool that can potentially replace radiographs in assessment of central line placement in preterm infants.

Conclusion

The protocol of POCUS that we propose is a reliable tool for assessing the central line positions in preterm infants.

Authors' contributions Reem Amer drafted the protocol, obtained the REB approval, performed the ultrasounds, and drafted the manuscript. Katya Rosovsky reviewed the protocol, interpreted the ultrasounds, and reviewed the manuscript. Yasser Elsayed reviewed the manuscript. Martin Bunge interpreted the ultrasounds and reviewed the manuscript. Aaron Chiu reviewed the protocol, provided statistician, and reviewed the manuscript.

Availability of data and materials All data can be accessed upon request.

Declarations

Ethics approval The institutional ethics board approval was obtained for prospective study and reviewed by the Biochemical Research Ethics Board.

Competing interests The authors declare no competing interests.

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