ARTICLE

Real-time ultrasound-guided lumbar puncture in the neonatal intensive care unit

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OBJECTIVE: To determine the rates of traumatic lumbar puncture (LP) and overall success rates using the real-time ultrasound-guided technique when performed by a neonatal point-of-care ultrasound provider.
STUDY DESIGN: Retrospective observational study of 17 infants in the neonatal intensive care unit who underwent a real-time ultrasound-guided LP between March 2015 and November 2016. Spearman's correlation was calculated.
RESULTS: The first attempt and overall success rates were 65% and 100%, respectively. The rate of nontraumatic LP was 69%. CSF RBC count was inversely correlated with both PMA (Spearman's correlation coefficient (r_s) = −0.74, $p = 0.0017$) and weight ($r_s = -0.74$, $p = 0.0015$) at the time of LP.
CONCLUSIONS: This study is the first to provide evidence of high success rates with real-time ultrasound-guided LP when performed by a neonatologist. Our data demonstrate feasibility in neonates over a broad range of weights, including premature infants as small as 750 g.

Journal of Perinatology (2021) 41:2495–2498; https://doi.org/10.1038/s41372-021-01152-0

INTRODUCTION

Lumbar puncture (LP) is one of the most common procedures performed in the neonatal intensive care unit (NICU) as it is required for the evaluation of many infectious, neurologic, or metabolic diseases in the newborn. Despite its frequent usage, providers are either unable to obtain cerebrospinal fluid (CSF) or the procedure results in a traumatic puncture in 15–50% of LPs [1–4]. Pediatric providers have increasingly taken advantage of point-of-care ultrasound (POCUS) to improve the safety and success rates of procedures. There are emerging data in non-NICU settings describing the use of ultrasound for LPs in the pediatric population [5–8]. Two basic approaches for ultrasound-guided LP have been described: static and dynamic. The static technique involves sonographically identifying and marking the optimal vertebral interspace followed by insertion of the spinal needle *without* ultrasound guidance [6]. The dynamic technique involves the same procedure followed by real-time ultrasound guidance to visualize and direct the needle into the subarachnoid space [9]. The static and dynamic techniques are sometimes referred to as ultrasound-assisted and ultrasound-guided, respectively [10]. In this paper we will use the term, real-time ultrasound guidance, rather than dynamic. The success rates and incidence of traumatic punctures are yet unknown for real-time ultrasound-guided LP in the NICU patient population.

METHODS

We conducted a retrospective observational study at a single, tertiary care, academic, urban NICU. We reviewed the electronic health record (EHR) of infants admitted to the NICU who had undergone a real-time ultrasound-guided LP between March 2015 and November 2016. Each patient's demographic information and laboratory data were extracted from the EHR. Baseline demographic data included birth weight, gestational age at birth, and the weight and age at the time of LP. The sonographer (JZS) was a neonatologist trained in POCUS. Ultrasound was performed using the Philips CX50 (Philips, Andover, MA, USA) or SonoSite X-Porte (FUJIFILM SonoSite, Bothell, WA, USA) ultrasound machines using the L15-7io or HSL25xp linear transducer, respectively. The ultrasound imaging and LP were performed with the patient in a sitting position [11]. The level of the conus medullaris and the level at which the spinal canal narrows was determined using ultrasound and marked with a surgical marking pen (Fig. 1, Supplemental Video 1). A detailed description of the ultrasound and marking procedures have been published [9]. The primary outcome was the CSF red blood cell (RBC) count. Secondary outcomes were the rate of successfully obtaining CSF fluid and the rate of nontraumatic LP as defined by a CSF RBC count of ≤1000 cells/uL [4]. Statistical analyses and data visualization were performed using *R* and the ggpubr and ggplot2 packages [12–14]. The study was approved by the Institutional Review Board at the Children's Hospital of Philadelphia.

RESULTS

Seventeen infants had a real-time ultrasound-guided LP as part of a sepsis, neurologic, or metabolic evaluation. The median gestational age at birth and the mean birth weight was 34 3/7 weeks (range 23 6/7–40 1/7 weeks) and 2036 ± 1081 grams (range 508–3460 g), respectively. At the time of LP, the median post-menstrual age (PMA) and the mean weight was 38 5/7 weeks (range 26 6/7–58 6/7 weeks) and 2983 ± 1311 grams (range 750–5880 grams), respectively. In 41% (7/17) of patients the real-time ultrasound-guided LP was performed after the treatment team had failed to obtain an acceptable CSF sample using the landmark LP technique. In 47% (8/17) of patients there were no

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Received: 30 December 2020 Revised: 7 June 2021 Accepted: 8 July 2021
Published online: 17 July 2021

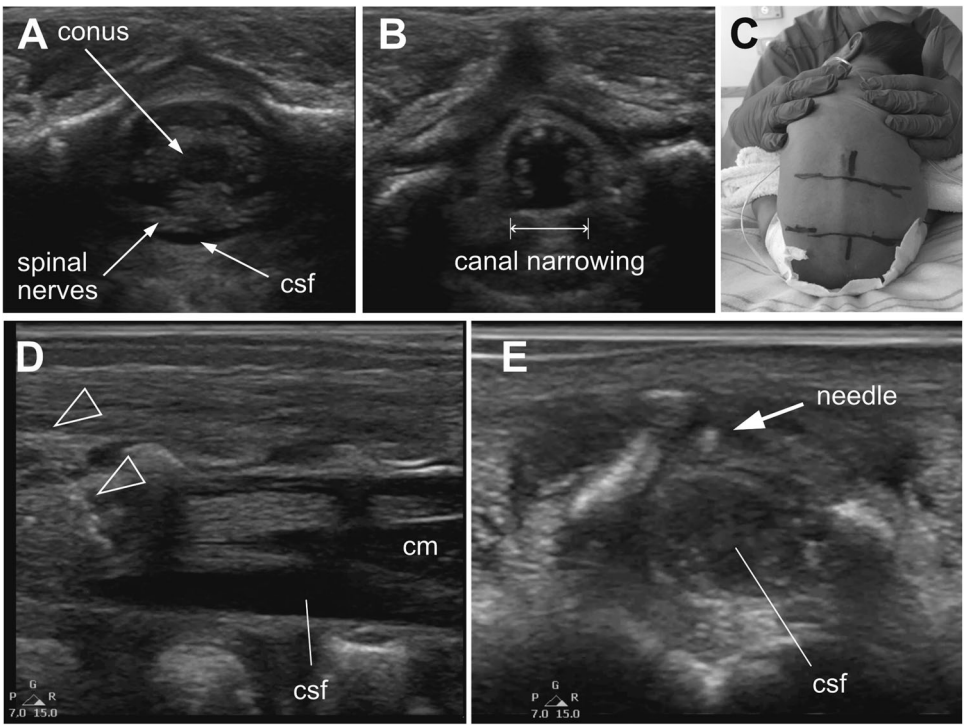

Fig. 1 Real-time ultrasound-guided lumbar puncture procedure. Transverse view of the lumbar spine showing the conus medullaris (**A**) and the level at which the spinal canal narrows (**B**). **C** Temporary skin markings showing the midline, the level of the conus medullaris, and the level of spinal canal narrowing. Sagittal (**D**) and transverse (**E**) views of the lumbar spine showing the needle being directed into the subarachnoid space under real-time ultrasound guidance. cm conus medullaris, csf cerebrospinal fluid.

Table 1. Rates of successful and nontraumatic lumbar puncture.

First attempt success rate	65% (11/17)
Overall success rate	100% (17/17)
Nontraumatic LP rate	69% (11/16)

prior LP attempts. It could not be determined if there were prior attempts in two patients. CSF was successfully obtained in all patients and was obtained on the first real-time ultrasound-guided attempt in 65% of encounters (Table 1). The median number of attempts was 1 (range 1–3). A CSF cell count was obtained in 16 of 17 patients. Of these 16 CSF samples, 69% were nontraumatic (Fig. 2). Of the eight CSF samples where there were no prior LP attempts, 100% were nontraumatic (Figs. 2, 3). Review of the data revealed a significant outlier with a CSF RBC count of 18,775 cells/uL (Fig. 3). This patient's weight and PMA at the time of the procedure were 5880 g and 45 weeks (98th percentile), respectively. The patient was treated for HSV encephalitis suggesting that the high CSF RBC count was due to the HSV encephalitis rather than a traumatic sample related to LP technique. After omission of this outlier, we found that both PMA (Spearman's correlation coefficient (r_s) = −0.74, $p = 0.0017$) and weight (r_s = −0.74, $p = 0.0015$) at the time of LP were significantly inversely correlated with CSF RBC count (Fig. 3).

DISCUSSION

A diagnostic or therapeutic LP is required for numerous neonatal diseases and is a frequent procedure in the NICU. Failure to obtain CSF or a traumatic puncture is common [1–4]. There are several possible explanations for the relatively low success rates. These include the training level of the provider, small size of the patient, cardiorespiratory instability, and anatomic considerations. Ultrasound provides an opportunity to overcome some of these challenges. Although the number of POCUS-trained providers is rapidly expanding, relatively few are proficient. Studies in the adult emergency department show that emergency medicine front line clinicians can quickly learn to identify spine landmarks by ultrasound [15–17]. While spine ultrasound in infants is straightforward, using real-time ultrasound guidance to coordinate needle insertion is technically more challenging. There are several additional benefits to using ultrasound for LPs. These include the ability to recognize sufficient CSF in the spinal canal, identification of hematoma from prior LP attempts, and the ability to visualize anatomic spinal cord abnormalities. Color Doppler is useful to identify the location of the blood vessels around the lumbar spinal cord (Fig. 4).

This study is the first to provide evidence of high success rates with real-time ultrasound-guided LP when performed by a neonatologist. Our data demonstrate feasibility in neonates over a broad range of weights, including premature infants as small as 750 g. We believe there is no lower weight limit when using this technique. In fact, infants who are very small have less vertebral ossification, thus allowing for better ultrasound visualization of the spinal canal. Although the sonographic windows are excellent in premature infants, the size of the spinal canal gets smaller with decreasing PMA. The smaller target may explain the data we observed with a higher incidence of traumatic LPs as both PMA and weight decreased. LP is commonly performed with the infant in a lateral recumbent position with hip and neck flexion. In premature infants, this may result in cardiorespiratory instability [18]. Ultrasound may allow for the LP to be performed without this flexion maneuver. Despite the fact that 41% of the LPs in this study were performed after an initial failed attempt using the landmark technique, a 100% success rate with 69% nontraumatic LP is better than most-reported NICU studies on the *initial* attempt [1–4].

There are limited data regarding success rates performing real-time ultrasound-guided LP in young children. There are no

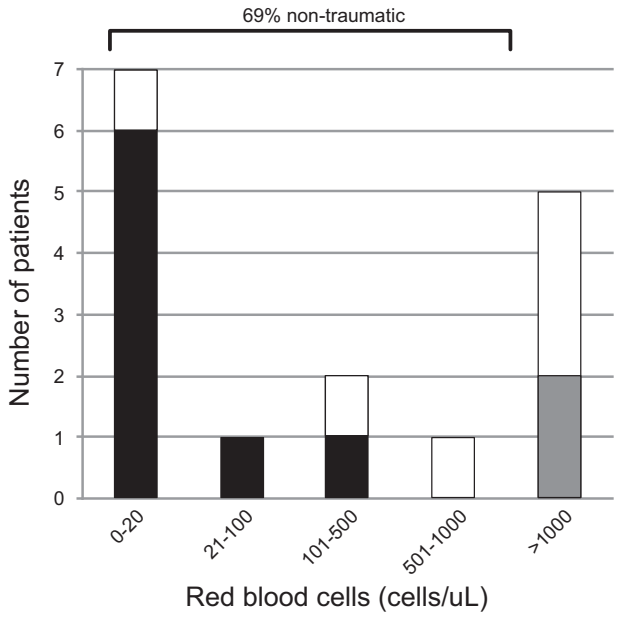

Fig. 2 The real-time ultrasound-guided technique is associated with a high incidence of non-traumatic lumbar punctures. Histogram showing the number of patients with the indicated cerebrospinal fluid red blood cell counts and the percentage of nontraumatic lumbar punctures (≤1000 cells/uL). First attempts are shown in black while attempts following an unsuccessful LP using the landmark technique are shown in white. Attempt data not available are shown in gray.

randomized controlled trials comparing the real-time ultrasound-guided technique with either the static or landmark techniques in young infants. To our knowledge, the following three studies comprise the entirety of the published literature describing the real-time ultrasound-guided (dynamic) technique in infants. None of these reported procedures were performed by POCUS providers. Coley et al. reported a case series of 19 patients aged 3–86 days who underwent a LP by an interventional radiologist using a midline sagittal approach. The PMA was not reported. They report a 58% success rate out of 26 encounters [19]. Wang et al. reported a case series of nine patients with an age range between 7 weeks and 16 years. Only one patient, a 5.1 kg 7-week-old, was under 6 months of age. These authors report a 100% success rate by neuroradiologists using a curvilinear probe in a transverse orientation with an in-plane needle approach [20]. Pierce et al. reported the largest case series of 107 LPs in 85 patients <6 months of age referred to interventional radiology [21]. The median age was 27 days (range: 2–176 days) and the median weight was 3.9 kg (range: 0.8–10 kg). The PMA was not reported. They report a 97% success rate and a 40% incidence of traumatic LP. Two recent meta-analyses have summarized the available evidence for the *static* ultrasound technique [22, 23].

There are limitations of this study. Although this is the only published study describing the use of real-time ultrasound guidance to perform LP in NICU patients, there are a relatively small number of patients included. The success rates and traumatic LP rates may not be representative of a larger sample. Success rates are likely dependent upon several factors including prior LP experience, prior POCUS experience, quality of ultrasound equipment, patient size, and patient illness severity. This was a

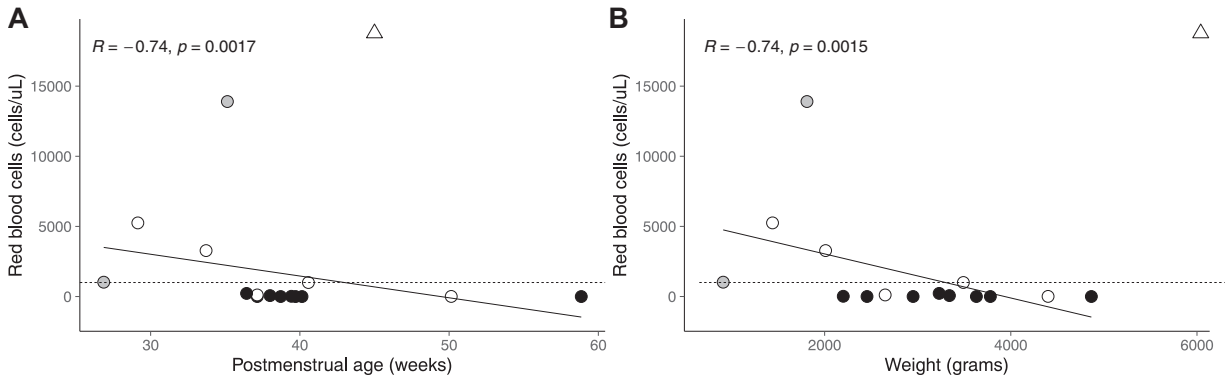

Fig. 3 Post-menstrual age and weight at the time of lumbar puncture are inversely correlated with CSF RBC count. Scatter plot showing that cerebrospinal fluid red blood cell counts correlate with post-menstrual age (**A**) and weight (**B**) at the time of lumbar puncture. First attempts are shown in black while attempts following an unsuccessful LP using the landmark technique are shown in white. Attempt data not available are shown in gray. The regression line, omitted outlier (triangle), and nontraumatic LP definition (dashed line) are indicated. The rho (R) and *p*-values were determined using Spearman's correlation.

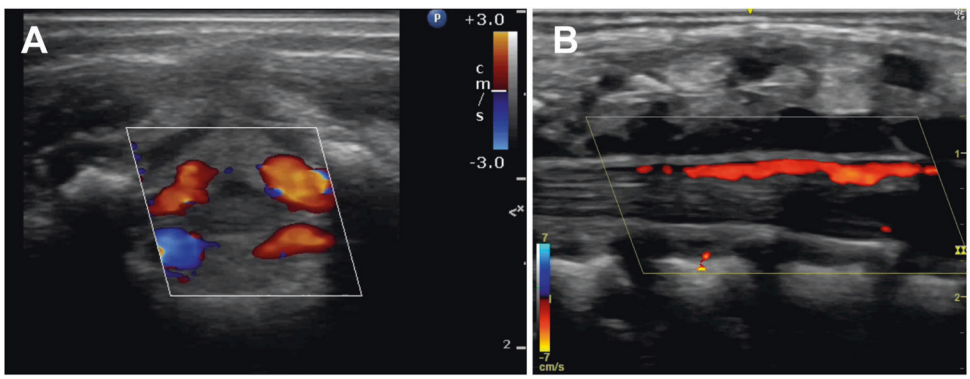

Fig. 4 Doppler ultrasound imaging of blood vessels in the region of the lumbar spine. Transverse (**A**) and sagittal (**B**) views showing flow in blood vessels at the level of the conus medullaris and cauda equina.

convenience cohort and our retrospective design may have resulted in missed patients. As 41% of the patients had a previous unsuccessful LP attempt using the landmark technique, a significant percentage of the traumatic LPs may be attributable to the prior failed attempt rather than to the real-time ultrasound-guided technique. This is supported by the absence of traumatic LPs among the ultrasound-guided LPs with no prior attempts. Hence, the incidence of traumatic punctures in this study may be an overestimate of the true incidence if the real-time technique had been used on the first attempt. All the LPs were performed by a single experienced POCUS-trained neonatologist. The success rates may not be generalizable to novice sonographers/providers. An ideal future study would be to prospectively randomize neonates to a first attempt traditional LP or a first attempt real-time ultrasound-guided LP with matching by provider experience.

In summary, trained neonatologists can perform real-time ultrasound-guided LP. The rates of successful and nontraumatic LP are high with this technique. In the near future, as more providers are trained in the use of basic ultrasound, technical performance improvements are likely. Research to determine optimal training and real-time ultrasound techniques is needed.

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AUTHOR CONTRIBUTIONS

JZS and MVF designed the study and wrote the manuscript. JZS performed the statistical analyses.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41372-021-01152-0.

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