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ORIGINAL ARTICLE

Neonatal neurosonography practices: a survey of active Society for Pediatric Radiology members

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Abstract

Background While neonatal brain US is emerging as an imaging modality with greater portability, widespread availability and relative lower cost compared to MRI, it is unknown whether US is being maximized in infants to increase sensitivity in detecting intracranial pathology related to common indications such as hemorrhage, ischemia and ventriculomegaly.

Objective To survey active members of the Society for Pediatric Radiology (SPR) regarding their utilization of various cranial US techniques and reporting practices in neonates.

Materials and methods We distributed an online 10-question survey to SPR members to assess practice patterns of neonatal cranial US including protocol details, use of additional sonographic views, perceived utility of spectral Doppler evaluation, and germinal matrix hemorrhage and ventricular size reporting preferences.

Results Of the 107 institutions represented, 90% of respondents were split evenly between free-standing children's hospitals and pediatric departments attached to a general hospital. We found that most used template reporting (72/107, 67%). The anterior fontanelle approach was standard practice (107/107, 100%). We found that posterior fontanelle views (72% sometimes, rarely or never) and high-frequency linear probes to evaluate far-field structures (52% sometimes, rarely or never) were seldom used. Results revealed a range of ways to report germinal matrix hemorrhage and measure ventricular indices to assess ventricular dilatation. There was substantial intra-institutional protocol and reporting variability as well.

Conclusion Our results demonstrate high variability in neurosonography practice and reporting among active SPR members, aside from the anterior fontanelle views, template reporting and linear high-resolution near-field evaluation. Standardization

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of reporting germinal matrix hemorrhage and ventricular size would help ensure a more consistent application of neonatal US in research and clinical practice.

Keywords Brain · Neonate · Neurosonography · Pediatric radiologists · Reporting · Society for Pediatric Radiology · Survey · Ultrasound

Introduction

The portability, widespread availability and relative lower cost of US compared to MRI optimize its utility as an imaging tool for the neonatal brain. The anterior fontanelle serves as an acoustic window in this age group and typically closes over widely variable ages by 24 months of age [1, 2]. Additional acoustic windows are used in neonates, providing more optimized views of specific anatomy. Conventional gray-scale US allows for anatomical detection of major intracranial pathologies while color and spectral Doppler US permit the assessment of macrovascular alterations accompanying intracranial pathologies.

Common indications for use of sonographic evaluation of the infant brain include screening for germinal matrix hemorrhage in premature infants, an abnormal increase in head circumference, ventriculomegaly, suspected hypoxic–ischemic injury and surveillance of known abnormalities, among others [3, 4]. In the setting of suspected hypoxic–ischemic injury, US can demonstrate the initial, subtle accentuation of the parenchymal gray–white differentiation, potentially leading to early diagnosis and management [3]. Head US is often performed in infants to establish a baseline before surgery or prior to the initiation of support therapies including hypothermia or extracorporeal membrane oxygenation (ECMO). Sonography can subsequently be used during ECMO to evaluate for hemorrhage or ischemia. Neurosonography can also readily assess for ventriculomegaly in infants who present with enlarging head circumference and increased intracranial pressure, and can be used to monitor ventricular size after shunt therapy. Vascular abnormalities such as a vein of Galen malformation and cerebral venous sinus thrombosis are readily evaluated using gray-scale imaging with the addition of color Doppler.

The American College of Radiology (ACR), American Institute of Ultrasound in Medicine (AIUM), Society for Pediatric Radiology (SPR) and Society of Radiologists in Ultrasound (SRU) have jointly published practice parameters for the performance of cranial US in the neonatal and infant brain. We surveyed active members of the SPR to quantify how frequently particular recommendations are used in clinical practice. Although cranial US is used to assess a wide range of clinical pathologies, we hypothesized that some US views are underutilized even though they have been shown to increase sensitivity in detecting intracranial pathology related to common indications for the examination. In addition, we sought to reveal any variability in the practice and reporting of intraventricular hemorrhage, spectral Doppler and ventricular indices.

Materials and methods

Members of the SPR Committee on Neonatal Imaging created a 10-question survey and submitted it to staff at the SPR for review, edits and eventual approval. We created the survey using SurveyMonkey (Momentive Inc., San Mateo, CA) and sent it via email to all active SPR members, allowing 1 month of time for completion and sending one reminder 2 weeks after the initial survey email. Surveys were sent to 1,183 members, with 151 completing the survey (13% response rate). The survey was anonymous apart from an option for respondents to list their clinical institution of practice and their email address for clarification of answers, if needed, by the authors.

The survey consisted of multiple-choice questions, ordinal scale responses, "check all that apply" responses, and an option for free-text responses (Online Supplementary Material 1). SPR staff collected survey answers, compiled results in Excel (Microsoft, Redmond, WA), and sent the results back to members of the neonatal imaging committee for analysis. Institutional consensus was defined as more than half of responses conforming to a single multiple-choice answer or a majority of answers within 1 numeric score of one another on the ordinal scale. If there was institutional consensus for a given survey question, this answer was counted toward the total. If there was no institutional consensus, no answer was recorded for a given question for that institution.

Results

A total of 1,183 survey invitations were sent, of which 620 were opened and 151 completed, resulting in the final response rate of 13% (151/1,183). Of the 107 institutions represented, 90% of respondents were split evenly between free-standing children's hospitals (50/107, 47%) and pediatric departments attached to a general hospital (46/107, 43%), meaning the pediatric hospital shares resources with an adult medical center. A small percentage (3/151, 2%) from separate institutions reported working at a community outpatient imaging center. Ten of 151 (7%) respondents, two of whom were from the same institution, answered *other*, with 6 describing practices associated with a larger medical center and/or adult hospital, 2 a military hospital, 1

Table 1 Practice setting and template reporting — responses per institution

Primary practice setting		Template reporting	
		Yes	No
Free-standing children's hospital	50/107 (47%)	31/50 (62%)	19/50 (38%)
Pediatric department attached to general hospital	46/107 (43%)	35/46 (76%)	11/46 (24%)
Community outpatient imaging center	3/107 (3%)	1/3 (33%)	2/3 (66%)
Other	8/107 (7%)	5/8 (63%)	3/8 (37%)
Total		72/107 (67%)	35/107 (32%)

a pediatric teleradiology service, and 1 a community hospital (Online Supplementary Material 2). Two-thirds of institutions (72/107, 67%) utilized template reporting for cranial US. Table 1 summarizes the distribution of imaging practice types and frequency of template reporting.

The utilization of various views, including institutional consensus, is summarized in Table 2. Nearly all institutions (106/107, 99%) always used still images and a large majority (75/107, 70%) always used cine loops as part of the standard examination. All institutions (107/107, 100%) reported using the anterior fontanelle approach as standard practice. Slightly more than half of the respondents (57/107, 53%) also reported using the mastoid view as standard. An additional third of respondents (30/107, 28%) frequently employed this view. Only a quarter of respondents (27/107, 25%) *always* or *frequently* used the posterior fontanelle approach. The transtemporal approach was *rarely* or *never* used by most respondents (73/107, 68%). No respondents reported using the foramen magnum approach as a standard technique and more than half never used this approach (57/107, 53%).

Table 3 presents a more in-depth analysis of how the posterior fontanelle view was used by our respondents, with about one-quarter reporting that it improves the detection of intraventricular hemorrhage and nearly a fifth indicating that it improves the detection of choroid plexus pathology and white matter injury. Thirty-eight percent indicated that it improves the diagnosis of tentorial abnormalities. There was moderate institutional consensus on the utility of the posterior fontanelle views, with 17/24 (71%) demonstrating consistency in its use among respondents from each individual institution; over a quarter of institutions had inconsistent utilization of the posterior fontanelle view among colleagues in the same practice.

A majority of institutions reported using high-resolution linear probe near-field evaluation *always* or *frequently* (78%), but only half of respondents used far-field evaluation with a liner transducer *always* or *frequently* (48%) (Table 2). Table 4 presents specific pathological indications for using the linear high-resolution probe, with the vast majority of those who used linear high-resolution evaluation finding it most helpful for pathology in extra-axial spaces (81%). This use had good institutional consensus (87.5%). These views were variably used to image deeper pathology, with just under half of respondents evaluating for white matter injury or assessing germinal matrix hemorrhage with the linear probe (Table 4).

About half of institutions represented by these survey responses used arterial spectral Doppler techniques for neonatal neurosonography (Table 5). Of these, about a fifth reported arterial indices with trends (22/107, 21%) or indices with reference values (22/107, 21%) rather than velocities. Just over a third used spectral Doppler to assess venous sinus thrombosis (38/107, 36%), with slightly fewer using it to evaluate hypoxic–ischemic injury (28/107, 26%). Over half (63/107, 59%) of respondents reported that they were "not sure" of how spectral Doppler assists in patient management.

Regarding germinal matrix hemorrhage reporting, more than half of respondents (59/107, 55%) reported grading germinal matrix hemorrhages on the initial study only and reporting descriptive changes on follow-up examinations (Table 6). About a quarter (29/107, 27%) re-graded with each follow-up US, and a small percentage (7/107, 7%) reported describing germinal matrix hemorrhages without grading.

Table 7 summarizes reporting trends in ventricular size. Half of institutions reported using sonographic indices (54/107, 50%), with the bifrontal horn diameter index being the most commonly used (30/107, 28%). There was very little inter- or intra-institutional consensus in ventricular size reporting.

There was relative intra-institutional concordance on US views (Table 2) and the use of a high-resolution linear probe to evaluate the extra-axial spaces (Table 4), but very little agreement within institutions regarding the utility of imaging through the posterior fontanelle (Table 3) and the use of spectral Doppler (Table 5). More than half of institutions were in agreement about grading germinal matrix hemorrhage on the first US only and reporting descriptive changes on follow-up (Table 6). About one-third were in agreement to re-grade germinal matrix hemorrhage on follow-up US.

Discussion

Brain US plays a crucial role in the screening and neuromonitoring of infants for whom repeated use of advanced imaging tools such as CT or MRI might not be desirable

Table 2 Sonographic views by institution type

View	Always	Frequently	Sometimes	Rarely	Never	No Reply	Concordance
Still images	106/107 (99%)	1/107 (1%)	0%	0%	0%		24/24 (100%)
Free-standing	49/50 (98%)	1/50 (2%)					18/18 (100%)
Attached	46/46 (100%)						6/6 (100%)
Other	11/11 (100%)						
Cine loops	75/107 (70%)	17/107 (16%)	12/107 (11%)	2/107 (2%)	1/107 (1%)		22/24 (92%)
Free-standing	36/50 (72%)	7/50 (14%)	5/50 (10%)	1/50 (2%)	1/50 (2%)		16/18 (89%)
Attached	33/46 (72%)	8/46 (17%)	4/46 (9%)	1/46 (2%)	0		6/6 (100%)
Other	6/11 (55%)	2/11 (18%)	3/11 (27%)	0	0		
Anterior fontanelle approach	107/107 (100%)	0%	0%	0%	0%		24/24 (100%)
Free-standing	50/50 (100%)						18/18 (100%)
Attached	46/46 (100%)						6/6 (100%)
Other	11/11 (100%)						
Mastoid view	57/107 (53%)	30/107 (28%)	7/107 (7%)	5/107 (5%)	4/107 (4%)	4	20/24 (88%)
Free-standing	26/46 (57%)	15/46 (33%)	1/46 (2%)	2/46 (4%)	2/46 (4%)		14/18 (83%)
Attached	27/46 (57%)	11/46 (24%)	6/46 (13%)	2/46 (6%)	0		6/6 (100%)
Other	4/11 (36%)	4/11 (36%)	0	1/11 (9%)	2/11 (19%)		
Posterior fontanelle approach	12/107 (11%)	15/107 (14%)	26/107 (24%)	33/107 (31%)	9/107 (8%)	12	17/24 (71%)
Free-standing	5/45 (11%)	5/45 (11%)	11/45 (24%)	18/45 (40%)	6/45 (14%)		13/18 (61%)
Attached	6/39 (15%)	9/39 (23%)	14/39 (36%)	10/39 (26%)	0	5	4/6 (100%)
Other	1/11 (9%)	1/11 (9%)	1/11 (9%)	5/11 (46%)	3/11 (27%)		
Transtemporal approach	8/107 (7%)	3/107 (3%)	18/107 (17%)	32/107 (30%)	41/107 (38%)	5	19/24 (79%)
Free-standing	2/46 (4%)	2/46(4%)	10/46 (23%)	13/46 (28%)	19/46 (41%)	4	14/18 (78%)
Attached	4/45 (9%)	1/45 (2%)	5/45 (11%)	18/45 (40%)	17/45 (38%)	1	5/6 (83%)
Other	2/11 (18%)	0	3/11 (27%)	1/11 (10%)	5/11 (45%)		
Foramen magnum approach		3/107 (3%)	10/107 (9%)	35/107 (33%)	57/107 (53%)	2	24/24 (79%)
Free-standing	0	0	4/48 (8%)	12/48 (24%)	32/48 (60%)	2	18/18 (78%)
Attached		1/46 (2%)	3/46 (7%)	18/46 (39%)	24/46 (52%)		6/6 (83%)
Other	0	2/11 (18%)	3/11 (36%)	5/11 (45%)	1/11 (9%)		
High-resolution linear probe near-field evaluation	59/107 (56%)	23/107 (22%)	20/107 (19%)	2/107 (2%)	1/107 (1%)		24/24 (100%)
Free-standing	30/48 (63%)	6/48 (12%)	12/48 (25%)	0	0	2	18/18 (100%)
Attached	21/46 (46%)	15/46 (33%)	7/46 (15%)	2/46 (4%)	1/46 (2%)		6/6 (100%)
Other	8/11 (72%)	2/11 (18%)	1/11 (10%)	0	0		
High-resolution linear probe far-field evaluation	30/91 (33%)	15/91 (16%)	22/91 (24%)	8/91 (9%)	18/91 (20%)		12/24 (50%)
Free-standing	12/41 (28%)	5/41(12%)	10/41 (23%)	6/41 (14%)	10/41 (23%)	1	10/18 (50%)
Attached	15/39 (38%)	7/39 (18%)	10/39 (26%)	2/39 (5%)	5/39 (13%)	5	4/6 (100%)
Other	3/11 (27%)	3/11 (27%)	2/11 (19%)	0	3/11 (27%)		
Color Doppler for vessel patency	37/107 (35%)	13/107 (12%)	27/107 (25%)	21/107 (20%)	9/107 (8%)		24/24 (83%)
Free-standing	28/50 (56%)	9/50 (18%)	8/50 (16%)	5/50 (10%)	0		18/18 (100%)
Attached	8/46 (17%)	3/46 (7%)	15/46 (33%)	12/46 (26%)	8/46 (17%)		6/6 (100%)
Other	1/11 (9%)	1/11 (9%)	4/11 (36.5%)	4/11 (36.5%)	1/11 (9%)		
Spectral Doppler for velocity, waveform analysis, and/or resistive index measurement	19/107 (18%)	10/107 (9%)	29/107 (27%)	25/107 (23%)	18/107 (17%)	6	18/24 (75%)
Free-standing	10/44 (23%)	6/44 (14%)	10/44 (23%)	9/44 (20%)	9/44 (20%)	6	12/18 (67%)
Attached	8/46 (17%)	3/36 (8%)	15/46 (32%)	12/46 (26%)	8/46 (17%)		
Other	1/11 (9%)	1/11 (9%)	4/11 (36.5%)	4/11 (36.5%)	1/11 (9%)		

Table 3 What is your opinion on the use of imaging through the posterior fontanelle? (check all that apply)

# of responses/total institutions of that type		Institutional consensus
Improves detection of intraventricular hemorrhage	27/107 (25%)	4/24 (17%)
Free-standing	9/50 (18%)	1/18 (6%)
Attached	13/46 (28%)	3/6 (50%)
Other	5/11 (45%)	
Improves detection of choroid plexus pathology	20/107 (19%)	3/24 (12.5%)
Free-standing	11/50 (22%)	1/18 (6%)
Attached	7/46 (15%)	2/6 (33%)
Other	2/11 (9%)	
Improves detection of white matter injury	25/107 (18%)	2/24 (8%)
Free-standing	13/50 (26%)	2/18 (11%)
Attached	11/46 (24%)	0/6
Other	1/11 (9%)	
Improves diagnosis of tentorial abnormalities	41/107 (38%)	7/24 (29%)
Free-standing	18/50 (36%)	7/18 (39%)
Attached	17/46 (37%)	0/6
Other	6/11 (54%)	
I do not routinely use this technique or rarely find it useful	23/107 (21%)	5/24 (21%)
Free-standing	13/50 (26%)	3/18 (17%)
Attached	19/46 (41%)	2/6 (33%)
Other	1/11 (9%)	

Table 4 If your primary site of practice routinely includes linear high-resolution evaluation, in which clinical situations do you feel that it adds to or clarifies exam interpretation? (check all that apply)

# of responses/total institutions of that type		Institutional consensus
Pathology in extra-axial spaces	87/107 (81%)	21/24 (87.5%)
Free-standing	41/50 (82%)	17/18 (94%)
Attached	37/46 (80%)	4/6 (67%)
Other	9/11 (81%)	
White matter injury	52/107 (49%)	9/24 (37.5%)
Free-standing	24/50 (48%)	7/18 (39%)
Attached	23/46 (50%)	2/6 (33%)
Other	5/11 (45%)	
Germinal matrix/intraventricular hemorrhage	53/107 (42%)	10/24 (42%)
Free-standing	22/50 (44%)	8/18 (44%)
Attached	23/46 (50%)	2/6 (33%)
Other	8/11 (73%)	
Other	6/107 (6%)	0
Free-standing	5/50 (10%)	
Attached	1/46 (2%)	
Other	0	
None of the above	6/107 (6%)	0
Free-standing	4/50 (8%)	
Attached	2/46 (4%)	
Other	0	

because of concerns of radiation, sedation and transport. Brain US is portable, less expensive than cross-sectional studies, and conveniently performed at the bedside. Our SPR neurosonography practice survey results demonstrate that while the institutions share some common practice algorithms, protocols could be more standardized within and across practices.

In terms of the scan protocol, published guidelines [1] recommend that images be acquired in the coronal and sagittal planes by sweeping through the anterior fontanelle from anterior to posterior and, as expected, most survey respondents used coronal plane imaging. The anterior fontanelle is the largest and the most accessible to use in a supine neonate, and has been highlighted as an acoustic window in this population for decades [5–7]. However, only half of survey respondents always used the mastoid view. This view is recommended to visualize posterior fossa structures [1, 8–10]. It is more technically challenging to obtain these views than through the anterior fontanelle, particularly in neonates who are intubated or have jugular lines or ECMO cannulas that limit positioning of the neck.

The posterior fontanelle approach is even less frequently used than the mastoid view, with only about a quarter of institutions using this view routinely. The guidelines mention the view through the posterior fontanelle, but do not highlight any particular application for this view. However, the literature has shown that the posterior fontanelle approach can improve the identification of intraventricular hemorrhage by better delineating periventricular white matter

Table 5 Spectral Doppler utilization — institution-specific

How do you report on arterial spectral Doppler results? (check all that apply)		Institution consensus
Indices with trends (improving, declining or sudden variation)	22/107 (21%)	3/24 (12.5%)
Indices (resistive and/or pulsatility index) with reference values	22/107 (21%)	4/24 (25%)
Velocities with reference values	4/107 (4%)	0
Velocities with trends	4/107 (4%)	0
Image acquired but values not reported	7/107 (7%)	1/24 (4%)
I do not routinely utilize arterial spectral Doppler in the evaluation of neonates	50/107 (47%)	6/24 (25%)
If your primary site of practice routinely includes spectral Doppler assessment, in which clinical situations do you feel it adds to exam interpretation? (check all that apply)		
Venous sinus thrombosis	38/107 (36%)	6/24 (25%)
Hypoxic–ischemic injury	28/107 (26%)	5/24 (21%)
Post-hemorrhagic hydrocephalus	17/107 (16%)	0
Ischemia	19/107 (18%)	1/24 (4%)
Extracorporeal membrane oxygenation (ECMO)	8/107 (7%)	0
Other (please specify)	38/107 (36%)	0
How does spectral Doppler assessment and reporting assist in the management of your patients? (check all that apply)		
Prognostic information	16/107 (15%)	2/24 (8%)
Timing of critical intervention (i.e. cooling protocol for HIE, shunt placement, etc.)	2/107 (2%)	2/24 (8%)
Timing of second cranial US	6/107 (6%)	1/24 (4%)
Timing of brain MRI	1/107 (1%)	0
Not sure	63/107 (59%)	4/24 (16%)

HIE hypoxic–ischemic encephalopathy

Table 6 Germinal matrix hemorrhage reporting

# of responses/total institutions of that type		Institutional consensus
Grade on first US only and report descriptive changes on follow-up	59/107 (55%)	16/24 (67%)
Free-standing	27/107 (25%)	11/18 (61%)
Attached	24/107 (22%)	5/6 (83%)
Re-grade with each follow-up US	29/107 (27%)	3/24 (12.5%)
Free-standing	14/107 (13%)	2/18 (11%)
Attached	15/107 (14%)	1/6 (17%)
Description without grade	7/107 (7%)	
Other (please specify)	8/107 (7%)	

abnormalities, choroid plexus and intraventricular hemorrhages, subarachnoid cisterns and brainstem [9, 11–14]. The more routine application of posterior fossa views could better identify pathology, and our survey results suggest that this view is underutilized in clinical practice.

It is appropriate that transtemporal views were infrequently used by our survey respondents because this approach is used to evaluate the circle of Willis. Applications are indication-specific in the neonatal age range, for example to monitor cerebral blood flow during cardiovascular surgery [15]. The transtemporal approach is frequently used in older children with sickle cell mutation or to assess the size of the 3rd ventricle as a reliable marker for dilatation of the greater ventricular system [16, 17]. The latter has limited relevance in the neonatal age group given their open fontanelles and we are not advocating for its inclusion in routine protocols. Nonetheless, for neonates whose fontanelle acoustic window is compromised for a variety of reasons including craniosynostosis, scalp edema or external devices, this paper serves to highlight that the transtemporal approach might prove to be another option when needed.

The foramen magnum approach was the least frequently used view for neonatal cranial US among our survey respondents. The guidelines note that these images might be useful to view the brainstem, cervical spine and craniocervical junction, specifically in cases of Chiari malformation. Indeed, these structures are less optimally visualized through the anterior fontanelle and the routine addition of this view might be low-yield to identify additional pathology, but familiarity with this scan approach can be useful in neonates with suboptimal transmastoid windows and to better delineate posterior fossa structures in symmetrical fashion [18].

The use of high-frequency linear transducers is vague in the established guidelines. It is not therefore surprising that the survey responses were mixed in reporting its clinical utility. A majority of our survey respondents used this probe for near-field evaluation. It is most frequently used to evaluate pathology in the extra-axial spaces, but studies have

Table 7 Ventricular size reporting

(# of responses/total institutions of that type)		Institutional consensus
How do you report changes in ventricular size?		
Sonographic indices of ventricular size	54/107 (50%)	11/24 (46%)
Free-standing	27/50 (54%)	9/18 (50%)
Attached	23/46 (50%)	2/6 (33%)
Other	4/11 (36%)	
Descriptive terms without measurement	39/107 (36%)	5/24 (21%)
Free-standing	17/50 (34%)	3/18 (17%)
Attached	19/46 (41%)	2/6 (33%)
Other	3/11 (27%)	
Other (please specify)	6/107 (6%)	
No answer	7/107 (7%)	
If you use a sonographic index for describing ventricular sizes, which index do you report?		
Bifrontal horn diameter	30/107 (28%)	8/24 (33%)
Free-standing	16/50 (32%)	7/18 (39%)
Attached	10/46 (22%)	1/6 (17%)
Other	4/11 (36%)	
Ventricular index or frontal horn ratio	22/107 (28%)	4/24 (33%)
Free-standing	11/50 (22%)	2/18 (11%)
Attached	10/46 (22%)	2/6 (33%)
Other	1/11 (9%)	
Fronto-occipital horn ratio (FOHR)	17/107 (10%)	3/18 (17%)
Free-standing	6/50 (12%)	0
Attached	10/46 (21%)	0
Other	1/11 (9)	
Fronto-temporal horn ratio (FTHR)	11/107 (3%)	0
Free-standing	2/50 (4%)	0
Attached	9/46 (20%)	0
Other	15/107 (14%)	0
Free-standing	5/50 (10%)	0
Attached	9/46 (20%)	0
Other	1/11 (9%)	
No answer	12/107 (11%)	

also shown utility in evaluating parenchymal detail such as echogenicity or cystic changes and alterations in gray–white differentiation [19]. In stroke, the gray–white differentiation can be better seen if a linear transducer is employed. In hypoxic–ischemic injury, the cortical and subcortical cystic encephalomalacia can be appreciated better with a linear transducer than a curvilinear transducer. The high-frequency linear transducers might prove to be a useful troubleshooting tool for discerning parenchymal abnormalities that are subtle or equivocal. Despite these applications, far-field evaluation was only used to evaluate white matter injury by about half of our survey respondents. The improved resolution of the high-frequency linear probe might enhance detection of germinal matrix hemorrhage, but again only half of our respondents cited this as an application (79/149, 53%). Although findings of hypoxic–ischemic encephalopathy and stroke are often suspected clinically, alterations in brain echogenicity, specifically basal ganglia and thalamus lesions and periventricular white matter changes, can have important implications for initiating treatment and predicting outcomes in this population. Therefore, it could be useful to optimize cranial sonography technique by including the use of the high-frequency linear transducer in this setting to document such findings. Occasionally, these pathologies are clinically occult, such as when the child is on ECMO, but they have major prognostic and treatment implications.

Gray-scale US is the mainstay technique for diagnosing vessel patency, but this technique can be bolstered by the application of color Doppler [20–23]. The application of color Doppler was used to assess vessel patency by nearly half of respondents (37/107 or 35%, always; 13/107 or 12%, frequently; 47% total). Spectral Doppler might also serve as a tool to assess blood flow in cranial US [22, 24]. Studies have also shown that decreased resistive indices in the anterior cerebellar artery on trans-fontanelle views correlate with findings of ischemic injury on MRI [25] and outcomes [26]. Researchers have also shown the value of spectral Doppler in assessing the timing for subsequent US or MR imaging and the timing of critical intervention such as shunt placement for post-hemorrhagic ventricular dilatation [27, 28]. Interestingly, the more frequent use of spectral Doppler for detecting venous sinus thrombosis (about a third of institutions) than hypoxic–ischemic injury (about a quarter) suggests that the application of spectral Doppler as a tool to assess findings relating to ischemia might be a target for education and research endeavors among SPR members. Given the narrow application for spectral Doppler in neonatal US, it is not inappropriate that 59% of survey respondents were "not sure" how Doppler assessment assists in patient management, further emphasizing that there are knowledge gaps in the interpretation and utility of this application.

The infrequent use of spectral Doppler despite these reports is also in part attributable to the lack of standardized guidelines for spectral Doppler-mediated clinical management. It is fair to say that complex pathophysiological processes governing brain perfusion regulation post neurologic injury are not solely manifested by changes in macrovascular flow dynamics. Furthermore, changes in spectral Doppler derived for macrovascular flow depend on factors other than the acute insult (e.g., co-morbidities such as congenital heart disease, medications, interventions such as hypothermia) and vary by gestational age. Improved understanding of how spectral Doppler could aid clinical management in select patient groups is needed to optimize the value of the technique. The low utilization of spectral Doppler among our respondents therefore seems appropriate and emphasizes the need for more research and education in this area.

Substantial variability also exists in reporting germinal matrix hemorrhage and intraventricular hemorrhage. While the majority of respondents grade the hemorrhage on the first US and report descriptive changes in hemorrhage and ventricular size on subsequent exams, up to a third of survey respondents reported the practice of re-grading on each follow-up US. Perhaps more important than the strictness of applying the grading criteria is the recognition that grades III–IV hemorrhages portend poorer outcomes and this should be communicated to the clinical team if there is progression from grades I or II hemorrhages. In this instance, a statement in the radiology report describing the evolving germinal matrix hemorrhage "now with ventricular dilation" or "now with periventricular hemorrhagic infarcts," or similar verbiage, would be important. Continued education on the pathophysiological implications of each grading level is also critical because the presence of a grade IV hemorrhage carries with it a higher risk of neurocognitive sequelae related to hemorrhagic venous infarction. Also important to recognize is the existence of isolated choroid plexus hemorrhages, which do not fit into the established grading criteria and thus warrant descriptive reporting at present [9].

Our results reveal variability in reporting changes in ventricular size. Half (54/107, 50%) of respondents reported measuring sonographic indices of ventricular size and over a third (40/107, 37%) reported using descriptive terms without measurement. The variable use of ventricular indices is in part attributable to a wide range of indices that have been described both the pediatric radiology and neurosurgery literature.

Further work is needed to compare and standardize the ventricular indices and this requires consensus with neonatology and neurosurgery specialists. One such study has been done to affirm correlation between the frontal-occipital horn ratio and MRI measurements of ventricular size [29].

In the future, improvements in three-dimensional (3-D) ventricular volume quantification might obviate the need for two-dimensional (2-D) ventricular size measurements. A 3-D representation might more accurately measure true volume than 2-D representative measurements. Perhaps this would be a useful application for an algorithm [30].

The primary limitation of this study is the response rate (13%, 151/1,183), which makes the data gathered less likely to reflect true clinical practice. However, 107 institutions are represented in this survey, which is a substantial percentage of those surveyed. Perhaps some institutions designated limited respondents or defaulted to those who practice primarily in the US subsections. This might partially explain the low individual response rate. As with any survey, there is sampling error because respondents self-select to answer topics of interest. With responses relatively split between free-standing children's hospitals and pediatric departments attached to a larger medical center, we found little difference in the type of institution in most responses. The number of questions was also limited to 10 with picklists so as not to overwhelm the respondents; however, this did require a narrower scope of the survey and might not have elucidated the routines performed at all practices. The survey did offer a number of open-text responses as a way to gather more information. Despite its limitations, this survey provides insight into the practices of pediatric radiologists in the performance and interpretation of neonatal head US.

Conclusion

The SPR survey results suggest that while standardized approaches to performing and reporting brain US exist, there is institutional variability in scan indications, protocols and interpretations. These results might be useful in guiding future education and research efforts by the SPR. Further improvements in the standardization of brain US in the clinical setting would undoubtedly enhance brain US implementation, trainee education, clinical trial reporting, multi-institutional collaborations and, most importantly, guidance of clinical care.

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Declarations

Conflicts of interest None

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