Impact of Targeted Neonatal Echocardiography on Patent Ductus Arteriosus Management in a Canadian Tertiary Care Neonatal Unit: A Retrospective Cohort Study

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Abstract

Objective Comprehensive assessment of hemodynamic significance of a patent ductus arteriosus (PDA) is a common indication to perform targeted neonatal echocardiography (TNE). Impact of implementation of such an assessment on PDA management decisions remains to be reported. The objective of this study is to compare PDA-related hemodynamic information and PDA treatment decisions before and after introduction of TNE service.

Study Design This was a retrospective cohort study at a tertiary level neonatal intensive care unit in Southwestern Ontario. We investigated two time periods: Epoch-1 (non-TNE 2013–2016) versus Epoch-2 (TNE 2018–2021). We included neonates < 32 weeks with PDA. Data on baseline clinical characteristics, PDA-related echocardiographic parameters, PDA treatment details, and relevant long-term outcomes were collected. Primary outcome was defined as PDA treatment rates and need for multiple courses. Secondary outcomes included availability of PDA hemodynamic data and neonatal mortality/morbidity (PDA-related)

Results A total of 275 neonates were included. A total of 162 were assessed by conventional echocardiography in Epoch-1, whereas 113 were assessed by TNE in Epoch-2. Baseline clinical characteristics were similar. Epoch-2 had more echocardiographic assessments per patient of 2.7 (±1.8) versus 1.9 (± 1.3), $p < 0.001$ in Epoch1. The mean postnatal age at first echocardiographic assessment was higher in Epoch-2 (12.7 days [± 14.6]) than in Epoch-1 (7.9 days [± 10.4]), $p < 0.001$. Comprehensive hemodynamic assessment of PDA-related echocardiographic parameters such as PDA size, shunt pattern, effect on systemic circulation, and pulmonary circulation were higher in Epoch-2. Overall, PDA treatment rates were comparable in the two time periods. The use of multiple courses of treatment was higher in Epoch-1 than in Epoch-2 (47.8 vs. 31.7%, $p = 0.047$). In Epoch-1, neonates received PDA treatment earlier than in Epoch-2.

Conclusion With the implementation of the TNE service, increased echocardiographic evaluations per patient were completed with availability of more comprehensive hemodynamic information about PDA. PDA treatment rates were similar in the two epochs, but need for multiple courses were less in TNE era.

Keywords
- targeted neonatal echocardiography
- patent ductus arteriosus
- premature
- neonates

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Key Points

- TNE allows comprehensive hemodynamic assessment of PDA.
- Implementation of dedicated TNE service led to increased use of echocardiography to assess PDA.
- Standardized hemodynamic assessment of PDA may allow improved individualization of treatment need.

Targeted neonatal echocardiography (TNE) refers to a bedside, goal-oriented, limited cardiac assessment that is performed by a neonatologist with the intention to answer a specific clinical question.[1–3] Clinical conditions where TNE has been helpful in guiding clinical management include patent ductus arteriosus (PDA), cardiovascular instability, persistent pulmonary hypertension, and congenital diagrammatic hernia. Assessment of the PDA remains the most common indication for requesting TNE.[4–6] Incidence of PDA in preterm neonates is approximately 15 to 40%, with a range between 50 and 65% in very low birth weight neonates (<1,000 g).

Using clinical assessment alone to determine the clinical significance of a PDA can lead to incorrect assumptions and unnecessary treatment interventions. Echocardiography remains the diagnostic modality of choice to assess the presence or absence of PDA.[7–9] Over the past few decades, a body of literature has emerged presenting individual echocardiographic parameters that suggest the hemodynamic significance of the PDA.[10,11] The synthesis of clinical findings in conjunction with echocardiographic parameters provides a rational method of determining the need for treatment.[12,13] In the absence of a TNE service, the decisions surrounding PDA treatment are either clinically based or are based on echocardiographic reports provided by pediatric cardiologists. However, with the evolution of TNE, trained neonatologists can utilize TNE to formulate decisions for PDA treatment. In our center, a TNE-based hemodynamic consultation service was implemented in 2018. Since its establishment, PDA treatment is based on recommendations of the TNE team that considers clinical findings in conjunction with echocardiographic parameters. Prior to that, the treatment of PDA was either based on clinical decisions alone or guided by consultation done by pediatric cardiologists, who reviewed and interpreted standard pediatric echocardiography obtained by trained sonographers.[14–17]

Our present study aimed to evaluate how the implementation of TNE-based hemodynamic consultation has affected the method of echocardiographic assessment of PDA and its impact on the therapeutic decisions being implemented for PDA treatment.

Materials and Methods

Study Design and Methods

This was a retrospective cohort study that included all preterm neonates who were admitted to a tertiary care neonatal intensive care unit and had TNE or cardiology consultations for PDA assessment. Institutional ethics approval (WREM 119294) for conduct of the study was obtained.

This center is a high-risk, fetal–maternal center and is one of the largest tertiary perinatal centers in Canada with around 5,700 newborns deliveries per year, admitting an average of 1,000 neonates per year. We investigated two time periods: Epoch-1 consisting of the cardiology era from January 2013 to December 2016 versus Epoch-2 of the TNE era from January 2018 to December 2021. Neonates < 32 weeks' gestational age (GA) who had a diagnosis of PDA during these two predefined periods were included in the study. We excluded any neonates < 32 weeks' GA with hemodynamically significant congenital heart diseases (except for atrial septal defect and ventricular septal defect), chromosomal anomalies, as well as neonates whose date of birth coincided with the temporary pause in TNE service at our center from June 2019 to November 2019. Prior to the TNE program, all the echocardiographic assessments for PDA were done by the local pediatric cardiology team. The clinical team would then review the echocardiography report by pediatric cardiology team and make a management decision. There were no guideline surrounding PDA treatment in Epoch-1 and treatment agent was up to the discretion of the managing physician. Nonsteroidal anti-inflammatory drugs namely indomethacin and ibuprofen were commonly used and less commonly acetaminophen. With the establishment of TNE services, a comprehensive PDA hemodynamic assessment utilizing a standardized imaging protocol and hemodynamic parameters was introduced to make clinical recommendations for PDA treatment by the hemodynamic consultation team. The hemodynamic consultation team consisted of neonatologists with additional training in TNE In Epoch-2, the first-line agent for pharmacological treatment was acetaminophen 15 mg/kg/dose every 6 hours for 7 days as outlined in the local PDA treatment guideline. In Epoch-2, posttreatment TNE was conducted within 7 days of treatment completion. Baseline characteristics, PDA treatment details, and relevant neonatal short-term outcome data were collected from paper and electronic charts. PDA-related echocardiographic data were collected from the echocardiographic report or the consultation notes. Echocardiographic images were not reviewed for this study.

Primary outcome was defined as PDA treatment rates and need for multiple courses. Secondary outcomes included availability of PDA hemodynamic data, neonatal mortality, and PDA-related morbidities such as pulmonary hemorrhage, bronchopulmonary dysplasia (BPD), necrotizing enterocolitis (NEC), intraventricular hemorrhage, survival to discharge, days to full feeds, days on respiratory support, and need for PDA ligation.

Sample size was based on convenience in keeping with the retrospective nature of the study.

Statistical Analysis

Continuous variables were summarized using means and standard deviations (SDs), and groups were compared using independent *t*-tests (or Mann–Whitney U tests, as appropriate). Categorical variables were summarized using frequencies and percentages, and groups were compared using chi-square tests (or Fisher's exact tests, as appropriate). All analyses were conducted using SPSS version 18 (IBM Corp., Armonk, NY), and *p*-values <0.05 were considered statistically significant.

Results

A total of 295 preterm neonates <32 weeks' GA were reviewed during the study period; 20 were excluded due to incomplete echocardiography reports, congenital heart disease, and congenital anomalies. The remaining 275 neonates were included in the study: 162 were assessed by conventional echocardiography in Epoch-1 (Cardio 2013–2016) and 113 were assessed by TNE in Epoch-2 (TNE 2018–2021; ►Fig. 1).

Baseline clinical characteristics were similar in the two time periods, except that postnatal age for the first echocardiogram was earlier in Epoch-1 with mean (± SD) days of 7.9 (± 10.4) compared with Epoch-2 with means (± SD) days of 12.7 (± 14.6), $p < 0.001$ (►Table 1).

Table 1 Baseline characteristic of the study participants

Variables	Epoch-1 (cardiology Epoch) $N = 162$	Epoch-2 (TNE Epoch) $N = 113$	*p*-Value
GA (wk), mean (SD)	26.5 (2.3)	26.1 (2.1)	0.185
BW (g), mean (SD)	1,005 (360)	915 (275)	0.103
Male sex, *n* (%)	85 (52.5)	68 (60.2)	0.206
Apgar score at 5 min, mean (SD)	6 (2)	6 (3)	0.271
C-section, *n* (%)	78 (48.1)	64 (56.6)	0.166
Antenatal steroids, *n* (%)	70 (43.2)	45 (40.2)	0.617
Suspected/confirmed chorioamnionitis, *n* (%)	13 (8)	6 (5.3)	0.382
Age at first echo, mean (SD)	7.9 (10.4)	12.7 (14.6)	<0.001

Abbreviations: BW, birth weight; C-section, cesarean section; GA, gestational age; SD, standard deviation.

Echocardiographic assessment per patient per year was significantly higher in Epoch-2 at a mean (± SD) of 2.7 (± 1.8) compared with Epoch-1 mean (± SD) of 1.9 (± 1.3), $p < 0.001$. There was significantly more echocardiographic information

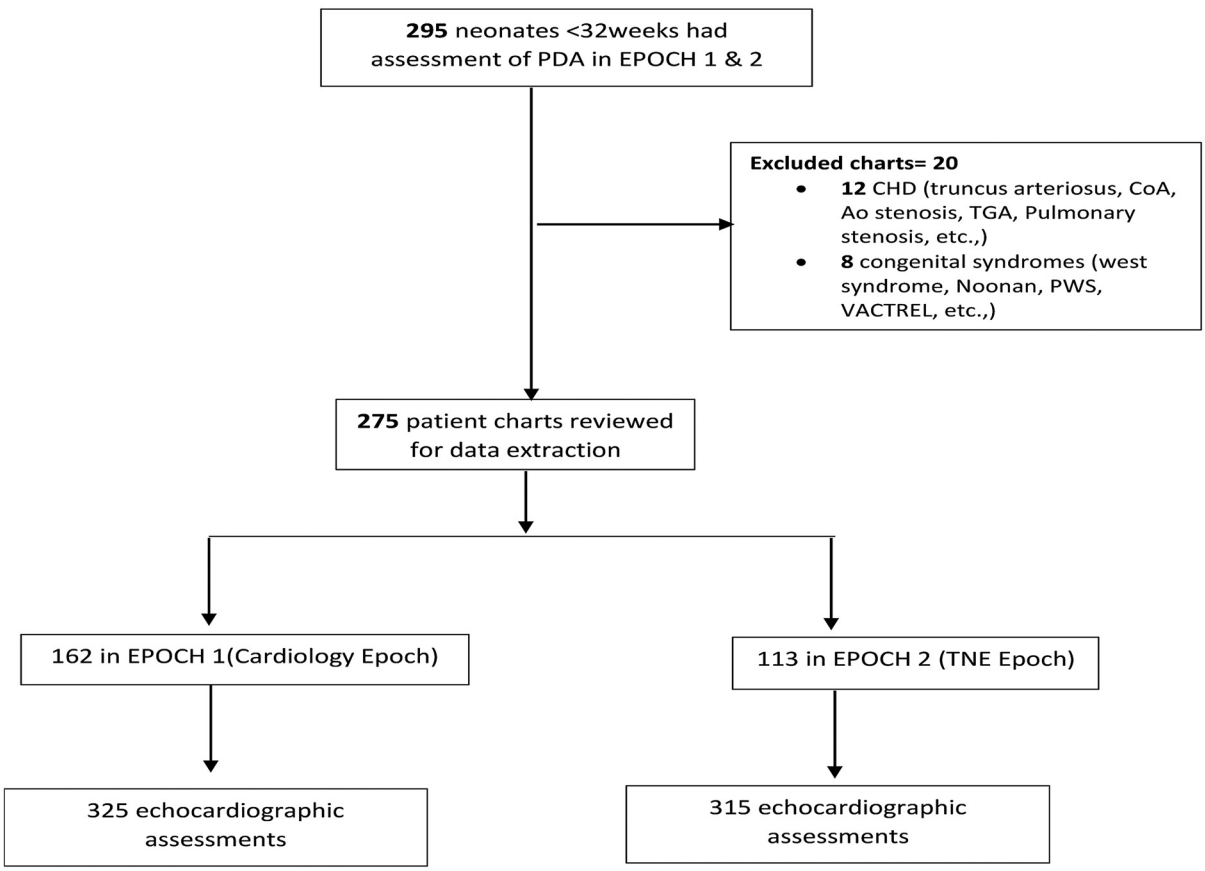

Fig. 1 Study flow diagram. CHD, congenital heart defects; CoA, coarctation of aorta; PDA, patent ductus arteriosus; PWS, Prader–Willi syndrome; TGA, transposition of great arteries; TNE, targeted neonatal echocardiogram; VACTREL, vertebral/anal/cardiac/tracheoesophageal/renal/limb anomalies.

Table 2 Comparison of the echocardiographic hemodynamic information of patent ductus arteriosus reported between the two Epochs

Variables		Epoch-1 (cardiology Epoch) $N = 325$	Epoch-2 (TNE Epoch) $N = 315$	*p*-Value
Echo/patient, mean (SD)		1.9 (1.3)	2.7 (1.8)	<0.001
Information on PDA	Shunt pattern, *n* (%)	163 (51.1)	169 (65)	<0.001
PDA classification[b]	Classification based on size[c], *n* (%)	300 (93.8)	239 (91.9)	0.393
	Small, *n* (%)	81 (27.3)	81 (34)	
	Moderate, *n* (%)	149 (50.2)	84 (35.3)	0.002
	Large, *n* (%)	67 (22.6)	73 (30.7)	
Information on systemic circulation	Abdominal aorta, *n* (%)	153 (47.7)	107 (39.2)	0.038
	SMA, *n* (%)	0	63 (23.1)	<0.001
	Celiac artery, *n* (%)	0	66 (24.2)	<0.001
Information on pulmonary over circulation	La:Ao ratio, *n* (%)	277 (86.3)	164 (59.9)	<0.001
	Pulmonary vein s and d, *n* (%)	0 (0.0)	134 (49.1)	<0.001
	LVO, *n* (%)	0	162 (59.3)	<0.001
	Qp:Qs, *n* (%)	0	106 (38.8)	<0.001
	LA/LV dilatation comment, *n* (%)	295 (91.9)	156 (57.1)	<0.001
	Overall information on pulmonary over circulation[a] *n* (%)	0 (0.0)	137 (50.4)	<0.001

Abbreviations: d, diastolic; LA, left atrium; La:Ao, left atrial: aortic root; LV, left ventricle; LVO, left ventricular output; PDA, patent ductus arteriosus; Qp:Qs, pulmonary: systemic circulation; s, systolic; SD, standard deviation; SMA, superior mesenteric artery.
[a]Information of at least three markers of pulmonary over circulation available.
[b]Missing data on PDA classification for 3neonates in EPOCH 1 (reported as small to moderate PDA with no size measured) and 1neonate in Epoch 2 (reported as moderate to large PDA with size not measured).
[c]PDA classification refers to size classification based on either objective size measurement or subjective eye balling assessment available in the echocardiogram report.

on both systemic and pulmonary circulation during Epoch-2 compared with Epoch-1 as shown in ►Table 2.

PDA treatment rates were similar in the two time periods (54.2% Epoch-1 vs. 54% Epoch-2, $p = 0.969$; ►Table 3). There was a significantly higher use of multiple courses of treatment in Epoch-1 than in Epoch-2 (47.8 vs. 31.7%, $p = 0.047$). Post-treatment echocardiograms were performed more in Epoch-2 as opposed to Epoch-1, although this wasn't statistically significant. While neonates in Epoch-1 received PDA treatment earlier than in Epoch-2, outcomes such as pulmonary hemorrhage, BPD, NEC, survival to discharge, days to full feeds, and days on oxygen were comparable in the two time periods (►Table 3).

Discussion

The present study examined differences in echocardiographic interrogation of the PDA with the implementation of TNE service and analyzed the impact of such implementation on therapeutic decision-making surrounding PDA. We compared two cohorts in two distinct times periods: Epoch-1 where the PDA was assessed and treated based on pediatric cardiology recommendations, versus Epoch-2 where PDA treatment was based on TNE. We found that in Epoch-2, comprehensive information on echocardiographic parameters related to PDA was more consistently available. Overall PDA treatment rates were similar in the two time periods; however, in Epoch-2 there were a significantly higher number of echocardiographic assessments and a significantly decreased need for multiple courses of PDA treatment compared with Epoch-1.

In our study, echocardiographic information on the shunt pattern, pulmonary over circulation, and systemic hypoperfusion were available more frequently in the TNE era. Specifically, diastolic flow information in intestinal arteries, such as the celiac artery and superior mesenteric artery, was only available in the TNE era. Quantification of pulmonary over circulation using established parameters such as left ventricular output, pulmonary venous flow velocity, and mitral inflow velocity was noted in Epoch-2, whereas in Epoch-1, echocardiographic reports often mentioned subjective assessment of chamber dilatation rather than objective measures. The difference in echocardiographic information in the two periods was related to the use of a standardized imaging protocol used for TNE, which aimed to collect detailed information on the size of PDA as well as the volume of shunt based on the European Special Interest Group's publication on assessment of PDA.[18–20] Such comprehensive imaging protocols have evolved based on the recognition that ductal dimension alone has limitations in predicting hemodynamically significant PDA. There is still an ongoing debate on which parameter either singly or in combination has the best ability to delineate treatment needs. Efforts are ongoing to devise a scoring system that

Table 3 Comparison of impact on patent ductus arteriosus management and related outcome between the two Epochs

Variables	Epoch-1 (cardiology Epoch) $N = 162$	Epoch-2 (TNE Epoch) $N = 113$	*p*-Value
PDA treatment rates, *n* (%)	90 (54.2)	61 (54)	0.969
Multiple courses[a] of treatment, *n* (%)	43 (30.9)	17 (8.3)	0.001
Treatment agent for first course, *n* (%)			
Indomethacin	44 (49.4)	4 (6.3)	<0.001
Ibuprofen	19 (21.3)	4 (6.3)	
Acetaminophen	17 (19.1)	50 (79.4)	
Acetaminophen and Ibuprofen combination	9 (10.1)	5 (7.9)	
Posttreatment echocardiographic assessments for first course[b], *n* (%)	55 (61.8)	41 (76.4)	0.070
Posttreatment echocardiographic assessments for second course[b], *n* (%)	29 (67.4)	12 (80)	0.514
Posttreatment echocardiographic assessments for third course[b], *n* (%)	11 (68.8)	5 (100)	0.278
Need for ligation, *n* (%)	5 (2.1)	0	0.167
Days on invasive ventilation, mean (SD)	24.3 (21.4)	29.1 (24.7)	0.089
Days on any respiratory support, mean (SD)	53.3 (38.9)	60.8 (42.1)	0.143
Days to full feeds, mean (SD)	22.4 (17.4)	23.3 (21.6)	0.738
BPD, *n* (%)	72 (49.7)	61 (57)	0.248
Pulmonary hemorrhage, *n* (%)	31 (20.3)	26 (23.4)	0.538
NEC, *n* (%)	27 (17.6)	12 (10.7%)	0.116
Any IVH, *n* (%)	86 (53.1)	59 (52.2)	0.886
Severe IVH grade 3–4, *n* (%)	32 (19.8)	22 (19.6)	0.974
PVL, *n* (%)	1 (0.7)	5 (4.5)	0.086
Any ROP, *n* (%)	54 (36.5)	43 (39.4)	0.628
Survival to discharge, *n* (%)	137 (82.5)	96 (85)	0.592

Abbreviations: BPD, bronchopulmonary dysplasia; IVH, intraventricular hemorrhage; NEC, necrotizing enterocolitis; PDA, patent ductus arteriosus; PVL, periventricular leukomalacia; ROP, retinopathy of prematurity; SD, standard deviation.
[a]Multiple courses = two or more treatment courses.
[b]Echocardiographic assessment within 1 week of treatment completion.

may help clinicians in selecting the population that benefits most from treatment. While the role of scoring or the predictive ability of individual echocardiographic measures is beyond the scope of the present study, the TNE era represents a time period where the TNE neonatologists used comprehensive echocardiographic parameters to identify high-risk neonates with specific hemodynamic characteristics that warrant treatment. With this integrated approach, there were more assessments performed per patient and more hemodynamic information were presented in the TNE era. We speculate that the comprehensive assessment in the TNE era, with more consistent posttreatment echocardiographic assessments, would allow for a better selection of patients who would need repeated courses of treatment and help avoid unnecessary treatment. However, there are additional factors that need to be considered when interpreting the reduction in the need for multiple courses in Epoch-2. These factors include the higher postnatal age at echo assessment as well as different treatment agents in Epoch-2, both of which could directly affect primary treatment outcomes. Additionally, PDA treatment remains one of the most contentious topics in neonatal medicine with ongoing debates regarding merits of early aggressive treatments versus more conservative approach. The local hemodynamics consultation team synthesizes the echocardiographic information, clinical presentation of the neonate, and the best-available evidence to devise an individualized treatment plan for the patient. While this approach in the TNE era does have the potential to affect treatment rates, we do acknowledge the retreatment may be a representation of the temporal change in "treatment philosophy."

Interestingly, the overall treatment rate, or exposure to any PDA treatment, was similar in the two study periods. We could not demonstrate a significant reduction in overall treatment need, which could be related to our retrospective study design and convenience-based sample size. The need for PDA ligation was higher in Epoch-1 compared with Epoch-2 but not statistically significant. However, it is reassuring to see that irrespective of the method of assessment, mortality and morbidity rates in the two time periods were similar. Despite

a lower rate of retreatment, the outcome related to PDA-related morbidities did not increase in Epoch-2. It was also reassuring to see that there were no trends of over treatment in Epoch-2 given the increased evaluations and additional information provided with these assessments.

The longitudinal TNE assessment enables improvement in diagnostic precision for conditions that may not be evident clinically or challenging to delineate, particularly in preterm neonates with other concurrent morbidities. This helps to modify PDA management plans and individualize treatment decisions avoiding unnecessary exposure to therapeutic agents, which may have undesired side effects.[21,22] A recent study showed a systematic evaluation of PDA and physiology-based management improved outcomes in periviable neonates suggesting its safety even in the most fragile neonatal population.[23] However, there are potential negative impacts such as burden on infrastructure, increased cost to maintain such service, increased handling of vulnerable neonates, and increased risk of hindering physiological stability. As TNE implementation increases worldwide, in depth analysis of this balance should be evaluated in future studies.

We acknowledge that our study was limited by its retrospective design. Additionally, being a single-center study limited the generalizability of the results due to possibilities of center-specific disease modifiable factors and lack of control over confounding factors as well as missing data. However, this was the first study in a large cohort that demonstrates the impact of TNE on PDA-related therapeutic decisions.[24] The last decade has witnessed increasing implementation and integration of TNE and neonatal hemodynamic consultations within the framework of neonatal intensive care. Several studies show that TNE frequently impacts clinical decision-making.[25] Emerging literature also demonstrates a positive impact on patient outcomes, especially in patients with pulmonary hypertension, circulatory compromise, post-PDA ligation, and malposition catheter tips of central venous lines.[26] While it is speculated that TNE for PDA may greatly improve "streamlining" PDA treatment, our study is the first to demonstrate a significant impact of TNE on PDA management in preterm neonates.[27] Despite the growing popularity of TNE, it is far from being universal. In centers that do not have access to TNE and use cardiology consultation-based echocardiography, collaborations between cardiologists and neonatologists and the incorporation of comprehensive PDA imaging protocol may have a far-reaching impact.[28] Further refinement of PDA assessment using a standardized scoring system incorporating both echocardiographic and clinical parameters that can be validated in a prospective study may go a long way in guiding therapeutic decisions surrounding PDA.[29]

Conclusion

With the implementation of the TNE service, increased echocardiographic evaluations per patient were completed with availability of more comprehensive hemodynamic information about PDA. PDA treatment rates were similar in the two epochs but need for multiple courses were less in TNE era.

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Conflict of Interest
None declared.

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References

1 Mertens L, Seri I, Marek J, et al; Writing Group of the American Society of Echocardiography European Association of Echocardiography Association for European Pediatric Cardiologists. Targeted neonatal echocardiography in the neonatal intensive care unit: practice guidelines and recommendations for training. Writing Group of the American Society of Echocardiography (ASE) in collaboration with the European Association of Echocardiography (EAE) and the Association for European Pediatric Cardiologists (AEPC). J Am Soc Echocardiogr 2011;24(10):1057–1078
2 Sinha B, Mirochnick MH, Kumar S, Fujii AM. Targeted echocardiography in the neonatal intensive care unit. J Am Soc Echocardiogr 2012;25(03):361, author reply 361–362
3 Singh Y. Use of echocardiography in the neonatal intensive care unit. Paediatr Child Health 2022;32(09):351–356
4 Mertens L, Seri I, Marek J, et al; Writing Group of the American Society of Echocardiography (ASE) European Association of Echocardiography (EAE) Association for European Pediatric Cardiologists (AEPC) Targeted neonatal echocardiography in the neonatal intensive care unit: practice guidelines and recommendations for training. Eur J Echocardiogr 2011;12(10):715–736
5 Giesinger RE, Hobson AA, Bischoff AR, Klein JM, McNamara PJ. Impact of early screening echocardiography and targeted PDA treatment on neonatal outcomes in "22-23" week and "24-26" infants. Semin Perinatol 2023;47(02):151721
6 Van Overmeire B, Van de Broek H, Van Laer P, Weyler J, Vanhaesebrouck P. Early versus late indomethacin treatment for patent ductus arteriosus in premature infants with respiratory distress syndrome. J Pediatr 2001;138(02):205–211
7 Fanaroff AA, Stoll BJ, Wright LL, et al; NICHD Neonatal Research Network. Trends in neonatal morbidity and mortality for very low birthweight infants. Am J Obstet Gynecol 2007;196(02):147.e1–147.e8
8 Clyman RI. Mechanisms regulating the ductus arteriosus. Biol Neonate 2006;89(04):330–335
9 El-Khuffash AF, McNamara PJ. Neonatologist-performed functional echocardiography in the neonatal intensive care unit. Semin Fetal Neonatal Med 2011;16(01):50–60
10 Schindler T, Smyth J, Bolisetty S, et al. Early PARacetamol (EPAR) trial: a randomized controlled trial of early paracetamol to promote closure of the ductus arteriosus in preterm infants. Neonatology 2021;118(03):274–281
11 Singh Y, Gupta S, Groves AM, et al. Expert consensus statement 'neonatologist-performed echocardiography (NoPE)'-training and accreditation in UK. Eur J Pediatr 2016;175(02):281–287
12 Singh Y, Katheria A, Tissot C. Functional echocardiography in the neonatal intensive care unit. Indian Pediatr 2018;55(05):417–424
13 Paudel G, Joshi V. Echocardiography of the patent ductus arteriosus in premature infant. Congenit Heart Dis 2019;14(01):42–45
14 Babla K, Duffy D, Dumitru R, Richards J, Kulkarni A. Repeatability of PDA diameter measurements on echocardiography. Eur J Pediatr 2022;181(01):403–406
15 Harabor A, Soraisham AS. Utility of targeted neonatal echocardiography in the management of neonatal illness. J Ultrasound Med 2015;34(07):1259–1263

16 Hébert A, Lavoie PM, Giesinger RE, et al. Evolution of training guidelines for echocardiography performed by the neonatologist: toward hemodynamic consultation. J Am Soc Echocardiogr 2019; 32(06):785–790
17 Evans N. Echocardiography on neonatal intensive care units in Australia and New Zealand. J Paediatr Child Health 2000;36(02): 169–171
18 Kluckow M, Seri I, Evans N. Echocardiography and the neonatologist. Pediatr Cardiol 2008;29(06):1043–1047
19 Cabral NC, Figueira SANN, Zamith MM, et al. Neonatal performed echocardiography course: can we face it? J Perinatol 2023:1–6
20 Corsini I, Ficial B, Fiocchi S, et al; Study Group of Neonatal Cardiology of the Italian Society of Neonatology. Neonatologist performed echocardiography (NPE) in Italian neonatal intensive care units: a national survey. Ital J Pediatr 2019;45(01):131
21 Papadhima I, Louis D, Purna J, et al. Targeted neonatal echocardiography (TNE) consult service in a large tertiary perinatal center in Canada. J Perinatol 2018;38(08):1039–1045
22 Corredera A, Rodríguez MJ, Arévalo P, Llorente B, Moro M, Arruza L. [Functional echocardiography in neonatal intensive care: 1 year experience in a unit in Spain]Ann Pediatr (Paris) 2014;81(03):167–173
23 Giesinger RE, Rios DR, Chatmethakul T, et al. Impact of early hemodynamic screening on extremely preterm outcomes in a high-performance center. Am J Respir Crit Care Med 2023;208 (03):290–300
24 Pereira SS. Comparison of PDA diameter measurements using color and 2D echocardiography in newborn infants. J Neonatal Perinatal Med 2023;16(01):137–140
25 Negreiros Figueira SA, de Oliveira AC, Zamith MM, et al. Echocardiography performed by the neonatologist: the impact on the clinical management. Pediatr Res 2023;94(02):724–729
26 Kharrat A, McNamara PJ, Weisz D, Jain A. Merits and perils of targeted neonatal echocardiography-based hemodynamic research: a position statement. Can J Physiol Pharmacol 2019;97 (03):183–186
27 van Laere D, van Overmeire B, Gupta S, et al; European Special Interest Group 'Neonatologist Performed Echocardiography' (NPE) Application of NPE in the assessment of a patent ductus arteriosus. Pediatr Res 2018;84(Suppl 1):46–56
28 McNamara PJ, Sehgal A. Towards rational management of the patent ductus arteriosus: the need for disease staging. Arch Dis Child Fetal Neonatal Ed 2007;92(06):F424–F427
29 Conrad C, Newberry D. Understanding the pathophysiology, implications, and treatment options of patent ductus arteriosus in the neonatal population. Adv Neonatal Care 2019;19(03): 179–187