My Approach to Targeted Echocardiography in the Neonatal Intensive Care Unit – Is It Fundamental?

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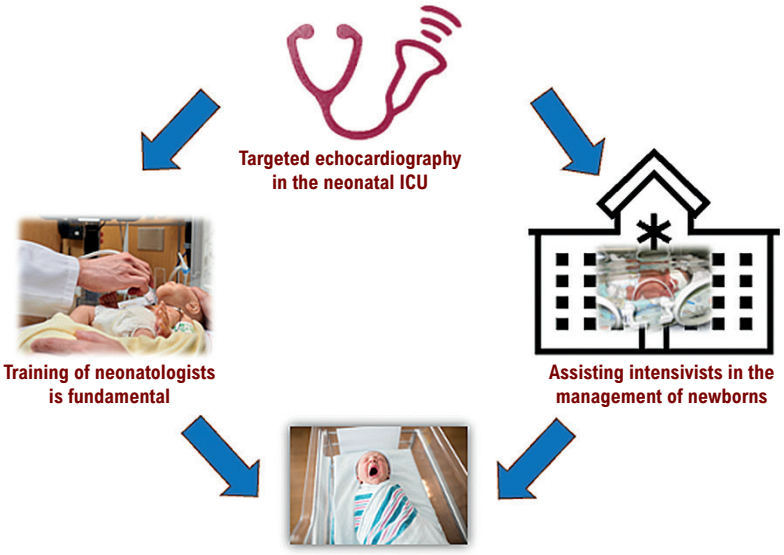
Central Illustration: My Approach to Targeted Echocardiography in the Neonatal Intensive Care Unit – Is It Fundamental?



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ICU: intensive care unit.

Abstract

With technological advancement, physical examination is no longer sufficient for a more accurate assessment of critically ill patients, especially in premature newborns where clinical signs may not be interpreted objectively. Therefore, there is great interest in training neonatologists in its practice, with major global centers already incorporating it permanently into their residency and continuing medical education programs. This review article discusses our experience in teaching institutionally focused echocardiography.

Keywords

Echocardiography; Neonatal Intensive Care Units; Newborn Infant.

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The clinic is sovereign!

As medical students in Brazil, we often hear the phrase "The clinic is sovereign," which, to a certain extent, is true; the clinic is essential for indicating and interpreting test results, as well as therapeutic management of our patients. However, in a scenario where the number of premature and critically ill newborns is increasing, physical examination is no longer sufficient to manage them assertively, especially in hemodynamic assessment, for example, repercussions of ductus arteriosus or even pulmonary hypertension. Accordingly, echocardiography has become an essential tool in the clinical management of newborns.[1,2]

Targeted neonatal echocardiography (TnECHO) can lead to changes in clinical management in up to 80% of critical cases.[3,4] Therefore, it is important to train neonatologists to perform TnECHO, given that they are at the frontline in the

management of newborns; it is also important to acquire portable echocardiography devices for neonatal intensive care units, since pediatric cardiologists are not often present in most services on a daily basis.

Training in TnECHO is already available in several neonatology residencies in Brazil,[5] although there is no standardization regarding the curriculum and course duration; nor is it possible to assess the training and retention of these doctors in performing TnECHO.

The term TnECHO encompasses a wide range of procedures, ranging from isolated qualitative assessment of cardiac function to more advanced forms of quantitative assessment of cardiac function and Doppler flow.

With respect to basic assessment, the latest TnECHO consensus published suggests that at least 25 assessments of cardiac function are necessary to enable neonatologist to perform TnECHO.[6] To perform advanced assessment, a recommendation has not yet been defined, ranging from 50 exams, as suggested by the Australasian Society for Ultrasound in Medicine,[7] to approximately 200 exams performed between 12 and 18 months of training by the European Society of Pediatrics.[8] In the United States, there is still no definition on the topic.

It is our understanding that TnECHO in neonatal intensive care units should be performed by neonatologists, and not by other pediatric specialties, since only a specialized professional can combine the interpretation of the data obtained with the clinical management of premature newborns, who are completely different from other pediatric age groups. However, it is important for neonatologists to be aware of the limitations of each form of training, always requesting echocardiography performed by pediatric echocardiographers during the patient's first examination, as soon as possible, or whenever there are doubts in relation to the presence of congenital heart defects.

Below, we describe our vision regarding the training of neonatologists.

Training neonatologists

Neonatologist training can be divided into basic and advanced, based on the duration and content of the course.

Basic course

The main objective of this course is to carry out a quick examination, at the bedside, to answer specific clinical questions, in critical situations such as shock, for example. In our experience, the content is taught by means of theoretical and practical classes. Theoretical classes cover the following topics: how to adjust and use the echocardiography device; basic concepts of Doppler analysis; acquisition of echocardiographic plans with identification of the corresponding cardiac structures; assessment of cardiac function, either qualitatively or using left ventricular shortening fraction; identification and interpretation of intra- and extracardiac shunts; cardiac blood volume through assessment of size and respiratory variation of the inferior vena cava; identification of signs of pulmonary hypertension and calculation of pulmonary pressure through tricuspid insufficiency; and assessment of the pericardium, identifying whether there is pericardial effusion with eventual signs of cardiac tamponade (Table 1).[5]

In practical classes, lasting 8 hours in total, students practice the acquisition of echocardiographic plans on real patients, for instance, adjusting the device to obtain the best images in order to recognize the normal anatomical structures of each plane, thus enabling them to recognize abnormal patterns, such as those occurring in congenital heart disease, cardiac dysfunction, or pericardial effusion.

Each student must perform at least eight complete exams under supervision (Figure 1).

At the end of the course, students undergo theoretical and practical assessment, where they perform 2 echocardiograms without supervision and answer a questionnaire for each exam, with general questions about the exams, for example: whether or not there are intra- and extracardiac shunts and, if so, which; whether heart function is normal or not; whether or not there is pericardial effusion; whether or not there is valve insufficiency and whether it is possible to estimate pulmonary pressure; whether they found any other additional information; and their final interpretation of the exam. This questionnaire, along with the images, are evaluated by the course instructor who assigns a grade indicating whether or not the student is qualified.

Six months later, the student must carry out two additional complete exams without supervision and send the images to the instructor, along with the answers to the previously sent questionnaire.

Advanced course

In order to take the advanced course, students must have basic prior knowledge of echocardiography and the unique characteristics of transitional neonatal circulation, including persistence of fetal pattern or pulmonary hypertension, repercussions of intra- or extracardiac shunts, and the suspicion of severe heart diseases, such as total anomalous drainage of the pulmonary veins, critical obstruction of the right or left ventricular outflow tract, or critical aortic coarctation. During this phase, students are able to indicate or contraindicate the initiation of prostaglandin E1 to maintain ductal patency.

Left ventricular assessment

Students learn to quantify systolic function by estimating

Table 1 – Theoretical syllabus of the basic functional echocardiogram course

Class 1: Principles of ultrasound
Class 2: Basic cardiac anatomy
Class 3: Left ventricular and right ventricular systolic function
Class 4: Assessment of fluid responsiveness
Class 5: Doppler assessment: valve flows and pulmonary hypertension
Class 6: Assessment of the pericardium
Class 7: Transitional neonatal circulation and cardiac shunts

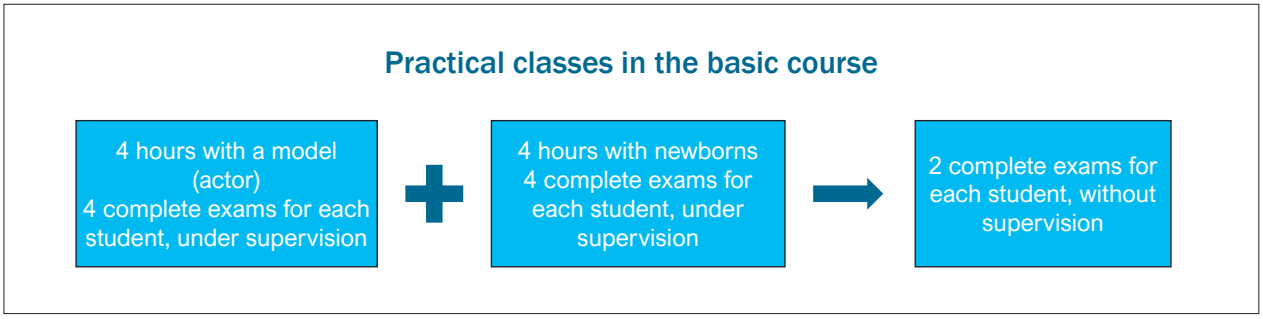

Figure 1 – *Schematic drawing illustrating the practical program of the basic course.*

left ventricular shortening fraction or ejection fraction, which can be obtained in M mode (in the parasternal short-axis plane at the level of the papillary muscles) or 2-dimensional mode (in the parasternal longitudinal plane at the level of the mitral valve chordae). We believe that the ejection fraction estimated by the biplanar Simpson method should only be performed in specific cases, as it requires more time and experience to perform. In the absence of significant shunts, we can still calculate cardiac output.[6] Normal values are displayed in Table 2. At every assessment, students are encouraged to critically interpret the values found according to their subjective assessment, in order to minimize underestimation of cardiac function.

Assessment of diastolic function is more complex, due to the high heart rates found in newborns. To put it simply, we usually find E < A waves on mitral Doppler of premature newborns. In these patients, the E > A wave may correspond to an increase in pulmonary venous return, as in the case of pulmonary hyperflow through a large ductus arteriosus. In mature newborns, an E > A wave is observed. We can also use isovolumetric relaxation time (IVRT), although it is technically difficult due to the fact that tachycardia is usually present. Hemodynamically significant ductus arteriosus tends to cause E > A waves in the mitral valve and shortening of the IVRT.

Right ventricular assessment

Function can be quantified using fractional area shortening (FAC) by tracing the right ventricular cavity in diastole and systole, which, in newborns, can be obtained in the apical 4-chamber or 3-chamber plane where the outflow tract is included,[9] using the following formula: FAC = end diastolic area – end systolic area / end diastolic area. We emphasize the importance of correctly tracing the endocardial border to include the trabeculations in the cavity. Normal values can vary between 25% and 45%, depending on gestational age and timing of birth.[10] Another parameter we teach is tricuspid annular plane systolic excursion (TAPSE), positioning the M-mode cursor between the lateral tricuspid annulus and the cardiac apex in the 4-chamber plane, reflecting the longitudinal contraction of the chamber. Normal TAPSE values vary according to gestational age,[11] and it is possible to use parameterization with the Z score available on the internet. Nonetheless, there are studies demonstrating that TAPSE values lower than 4 mm are related to the need for extracorporeal circulation and higher mortality in newborns with pulmonary hypertension.[12] Right ventricular cardiac output may also be calculated. The diastolic function of the right ventricle is not taught at the course, due to the limitation of lacking reference data in the literature.

Assessment of pulmonary hypertension

Students are encouraged to check for indirect signs of pulmonary hypertension, such as dilation of the right chambers, right ventricular systolic dysfunction, and inversion of intra- and extracardiac shunts. Additionally, in the advanced course, we recommend performing the following quantifications:

Assessment of pulmonary artery systolic pressure (PASP) through tricuspid insufficiency, when present, using the formula: PASP = 4 × maximum velocity of the tricuspid regurgitant jet^2 + right atrial pressure; considering end-diastolic pressure of approximately 5 mmHg. We emphasize the need to obtain adequate tricuspid regurgitant jet for better accuracy. It is important to consider that values below 35 mmHg are not always indicative of normal pulmonary pressure, since patients may have very low systemic systolic pressure, for instance, in conditions of cardiogenic shock, which would also reduce pulmonary systolic pressure. If there is pulmonary insufficiency, mean pulmonary artery pressure (MPAP) can also be measured using the following formula: MPAP = 4 × peak diastolic pulmonary regurgitation velocity^2 + right atrial pressure. However, the presence of hemodynamically significant ductus arteriosus may complicate assessment.

In the absence of significant tricuspid and/or pulmonary insufficiency, we can use the ratio of ejection time divided by pulmonary flow acceleration time, considering normal values < 4 (Figure 2). Nevertheless, it is important to underscore the technical limitations related to Doppler assessment in conditions of high heart rate and even in high-frequency mechanical ventilation or elevated pressures. We recommend performing time interval measurements at maximum spectral Doppler velocity to minimize these errors. We also consider the presence of the midsystolic notch in pulmonary flow on Doppler as a marker of a significant increase in pulmonary pressure.

In the event that direct objective measurements are not possible, students can evaluate other common findings in pulmonary hypertension in newborns, for example, rectification

Table 2 – Parameters for Evaluating Cardiac Function Taught with Reference Values

Tool	Technique	Reference Values
Fractional Shortening	M-Mode: Position cursors between the papillary muscles in the parasternal short-axis view. B-Mode: Measure cavity diameters at the internal edges at the level of the mitral valve chordae in the parasternal long-axis view.	30-45%
Ejection Fraction (Teicholz)	M-Mode: Position cursors between the papillary muscles in the parasternal short-axis view. B-Mode: Measure cavity diameters at the internal edges at the level of the mitral valve chordae in the parasternal long-axis view.	55-70%
Fractional Area Change (FAC)	Trace the right ventricle in the apical 4-chamber view or in the intermediate plane with a more pronounced anteriorization from the apical 4-chamber view, visualizing the right ventricular outflow tract, at end-diastole and systole. Formula: FAC = (end-diastolic area - end-systolic area) / end-diastolic area.	≥ 35%
Tricuspid Annular Plane Systolic Excursion (TAPSE)	In the apical 4-chamber view, position the cursor encompassing the lateral tricuspid annulus and the apex of the right ventricle.	Values vary with gestational age. Values less than 4 mm indicate a worse prognosis in neonatal pulmonary hypertension.
Left Ventricular Cardiac Output (LVCO)	Position the pulsed Doppler cursor at the aortic valve level in the apical 5-chamber view and trace the area obtained for the device to calculate the VTI. Measure the aortic annulus diameter from inner edge to inner edge in the parasternal long-axis view at its maximum diameter, with the valve open, in telesystole. Estimate heart rate according to the monitor or using the pulsed Doppler. LVCO = Heart rate (HR) × stroke volume (aortic VTI × area of the left ventricular outflow tract calculated by the device after measuring the aortic annulus).	150-300 ml/kg/min
Right Ventricular Cardiac Output (RVCO)	Parasternal short-axis view of the right ventricular outflow tract: Pulmonary VTI: place the pulsed Doppler cursor at the pulmonary valve annulus level and trace the area obtained. Measure the diameter of the pulmonary valve annulus at its maximum opening (telesystole). Use the same formula as LVCO.	150-300 ml/kg/min

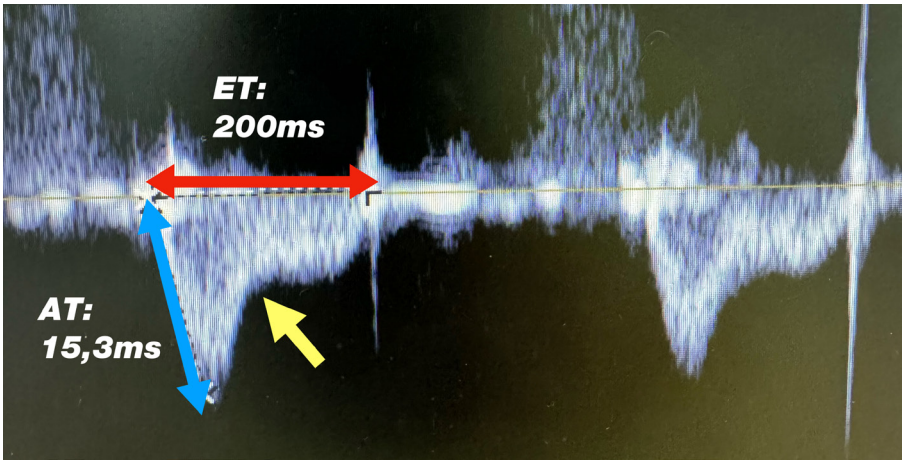

Figure 2 – *Spectral Doppler of pulmonary flow in a newborn with pulmonary hypertension. Note the presence of the mid-systolic notch (yellow arrow). The ratio between the ejection time (ET; red arrow) of 200 ms and the acceleration time (AT; blue arrow) of 15.3 ms was 13.*

of the interventricular septum during systole and the eccentricity index, which is calculated on the ventricular short axis, at the level of the papillary muscle of the mitral valve, dividing the diameter of the horizontal axis by the vertical axis of the ventricle, as shown in Figure 3. Values below 1.3 are considered altered.[13]

Note: In patients with significant pulmonary hypertension and in those with bronchopulmonary dysplasia, we recommend assessment of pulmonary vein flow velocities to rule out possible stenoses. Premature newborns under 29 weeks of gestational age should undergo a complete assessment of pulmonary flow hemodynamics at 8 postnatal weeks or 36 weeks corrected gestational age.[6]

Assessing the repercussions of ductus arteriosus

Patent ductus arteriosus is a common finding in newborns, with a high incidence in premature patients, and it is one of the topics that neonatologists most frequently ask about in courses.

The starting point that must be emphasized is the exact location of the measurement of the diameter of the ductus arteriosus, because, depending on the angle used to acquire the 2-dimensional image, the size may be overestimated. The measurement must be taken at the narrowest point (which is the real flow limiter) in the high parasternal plane (channel view) or in the suprasternal plane with angulation to the left, and it should be classified as small (< 1.5 mm), moderate (between 1.5 and 3 mm), or large (> 3 mm).[13]

Neonatologists assess the following echocardiographic findings in hemodynamically significant ductus arteriosus:

Ratio of the size of the ductus arteriosus to the left pulmonary artery, preferably using the high parasternal plane.[14] Ratios < 0.5 indicate a shunt of small magnitude, and > 1 indicate large magnitude;

Ductus arteriosus flow patterns on Doppler (Figure 4):

- Flow with end-diastolic velocity < 2 m/s indicates no restriction and presents a pulsatile pattern. This type of flow typically has important repercussions, and the channel is usually large.
- Flow with end-diastolic velocity > 2 m/s (diastolic velocity close to systolic velocity or diastolic velocity at least 50% of systolic velocity) indicates restrictive flow.
- "Increasing" flows are the ones that have a small component of flow from the pulmonary artery to the aorta (generally less than 30% of the cardiac cycle) and are found in the transitional period of pulmonary circulation. This pattern indicates a drop in pulmonary pressure and the possibility of future hemodynamic repercussions in the event that the ductus does not decrease in size or close spontaneously.
- Exclusive right-to-left flow or bidirectional pattern (right-to-left flow greater than 30% of the cardiac cycle) is the pattern found in pulmonary hypertension.

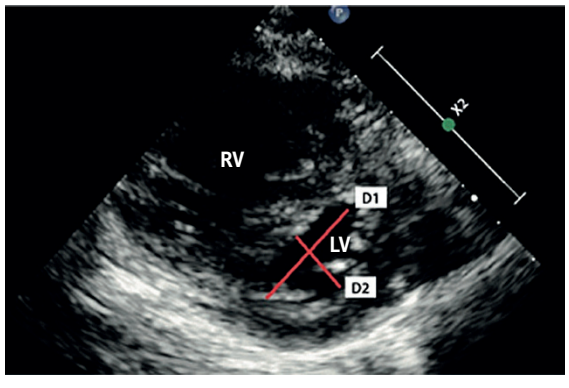

Figure 3 – *Two-dimensional image demonstrating the calculation of the eccentricity index: in the parasternal short-axis plane, dividing diameter 1 (D1) by diameter 2 (D2); values less than 1.3 are indicative of significant pulmonary hypertension. LV: left ventricle; RV: right ventricle.*

Signs of pulmonary hyperflow:

- Increased left ventricular cardiac output (major repercussion with values above 300 ml/kg/min);
- Dilation of the left chambers with a ratio between the aorta and the left atrium greater than 1.5 (consider the presence of interatrial communications as a limitation);
- Increased end-diastolic velocity in the left pulmonary artery (> 0.25 m/s);
- Mitral flow with E > A in premature infants and E > A in full-term infants or in the presence of mitral insufficiency;
- Increased velocity of venous return through the pulmonary vein (D wave > 0.5 m/s).

Signs of pulmonary hypoflow:

- Absence of anterograde diastolic flow in the descending aorta on pulsed Doppler;
- Presence of reverse diastolic flow in the descending aorta (indicative of important "steal" of systemic flow);
- Absence of anterograde diastolic flow in the mesenteric artery;
- Presence of reverse diastolic flow in the mesenteric artery (indicative of large "steal" of systemic flow).

Conclusions

Accordingly, we believe that performance of TnECHO is fundamental to excellent quality in the management of critical newborns, especially premature ones. We must remain committed to training neonatologists to perform TnECHO and recognize the method's limitations. Teaching programs are needed for remote areas where few medical specialties exist (Central Illustration).

Author Contributions

Conception and design of the research, Acquisition of data, Analysis and interpretation of the data, Statistical analysis, Obtaining financing, Writing of the manuscript and critical revision of the manuscript for intellectual content: Lianza AC, Morhy SS.

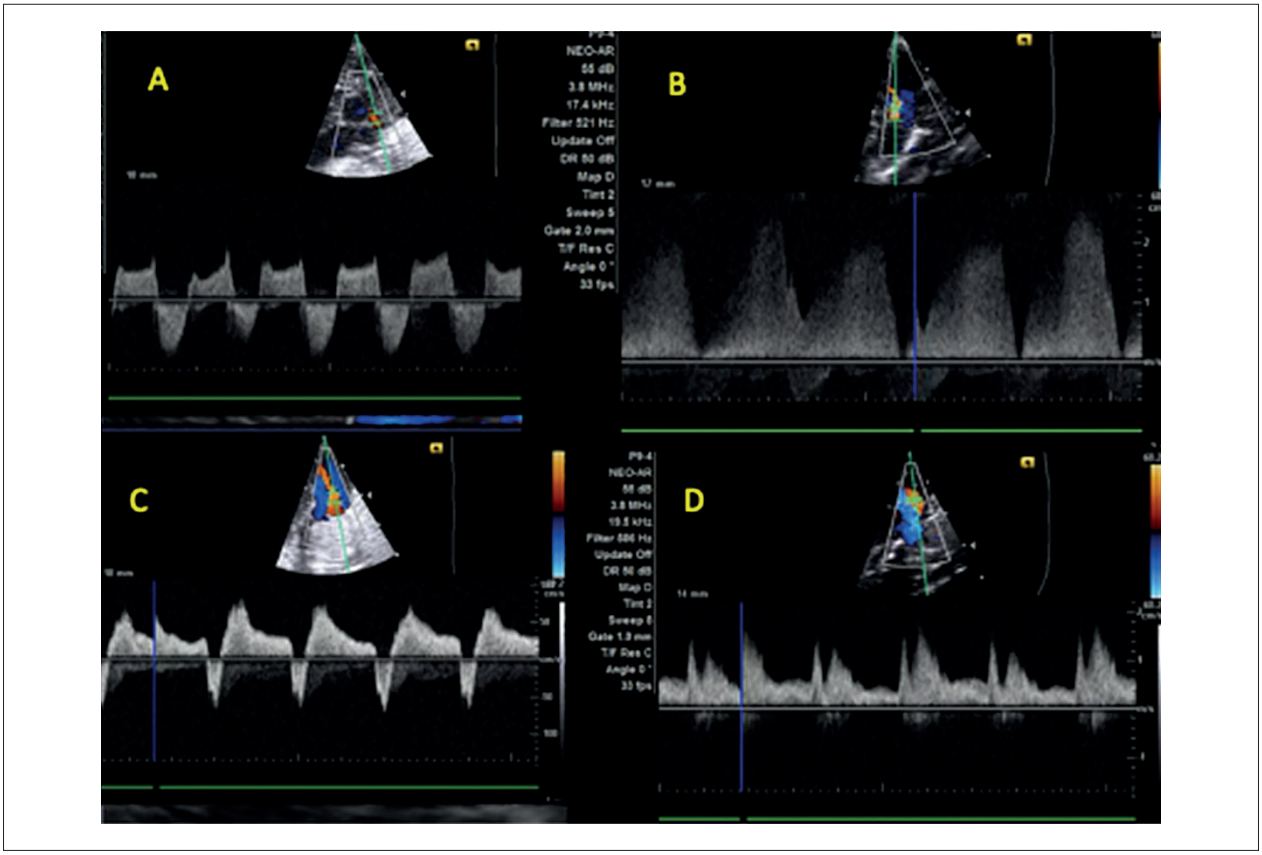

Figure 4 – *Spectral Doppler demonstrating different flow patterns of the ductus arteriosus. A: Bidirectional pattern. B: Continuous, restrictive pattern. C: Growing pattern. D: Pulsatile, non-restrictive flow from the aorta to the pulmonary artery.*

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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