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Echocardiography of the patent ductus arteriosus in premature infant

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Abstract

Management of the patent ductus arteriosus (PDA) in the premature infant has been a point of controversy for decades as smaller and earlier gestational age infants have been surviving. Increasing experience with catheter-based device closure has generated a new wave of interest in this subject. In this era, echocardiography plays a central role for collaboration within a multispecialty team. Reliability of echocardiography is improved by applying an institutionally derived standard approach to imaging, data collection, and reporting. The key aspects of both the physiology and anatomy of the PDA to distinguish infants that may benefit from intervention are described.

KEYWORDS

device closure, echocardiography, patent ductus arteriosus, premature infants

1 | INTRODUCTION

Patent ductus arteriosus (PDA) is associated with numerous complications in premature babies.[1] Hemodynamics of the PDA guide management. But anatomic features have gained importance with the growing experience in transcatheter device closure of the ductus in premature infants. Echocardiography is the single most useful tool to define both the anatomy and physiology of the PDA. Although echocardiographic evaluation of PDA has been previously described, this review presents a practically employable guide to relevant parameters in premature infants that facilitates the multidisciplinary collaboration needed for making therapeutic decisions.

2 | DISCUSSION

2.1 | Procedural, reporting, and technical considerations

The first echocardiogram (echo) should completely define the segmental cardiovascular anatomy and function. This study is best done early as progression of lung disease and ventilation-related artifacts can deteriorate the acoustic windows. Once a PDA has been diagnosed, the neonatologist will commonly order one or more follow-up studies, especially if the clinical course is worsening. These subsequent studies should adhere to an institutional protocol: the cardiologists (including interventionist) and neonatologists should agree on the imaging parameters desired and reported. The report summary should have a standard format that tracks serial changes from the previous echo as this is essential to optimize communication.

Although high-frequency probes (8-12 MHz) are most commonly utilized, lower frequency probes can provide better penetration from some of the unconventional surface "windows" available on these babies who, more often than not, are receiving conventional or high-frequency mechanical ventilation. Coordination of care with the bedside nurse for positioning, sedation and timing of the echo with other services (eg, intravenous line insertion) not only optimizes the images, but also minimizes transient ductal constriction which can mislead the physician from determining the dominant physiology. Blood pressure obtained close in time should be recorded and used for interpretation of the Doppler measurements that are reported.

2.2 | Anatomic considerations of the ductal region

Aortic arch anomalies must be ruled out on the first study. Any variance from a left arch with normal branching should be defined and noted in the report. Any deficiencies defining these thoracic vessels on the initial echo, are best highlighted in the summary and for supplementation at follow-up. Device closure of the PDA is contraindicated in the presence of a vascular ring as the ductus forms a part of the ring. A large PDA may mask the presence of coarctation of the aorta.

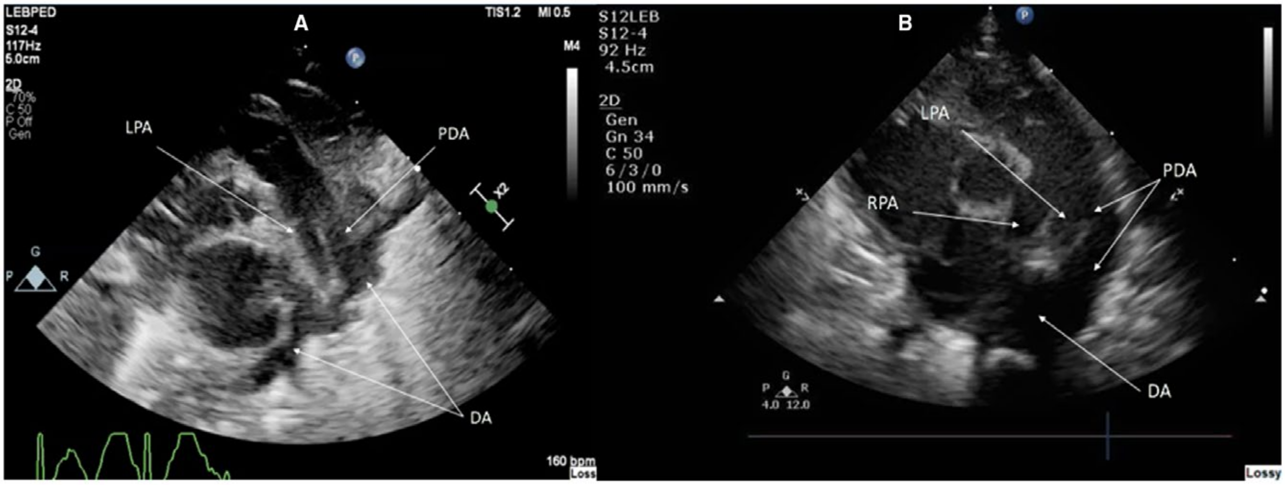

FIGURE 1 Echocardiographic images of the PDA. A, PDA in high parasternal view showing its superiorinferior extent, optimal for measuring its length and also the diameters (notice that the DA is displayed longitudinally which suggests that the imaging plane is closer to parasagittal plane rather than transverse). B, PDA in parasternal short-axis view showing its anteroposterior extent, the diameters can be measured but it is not optimal for measuring its length (notice that DA is displayed axially suggesting that the imaging plane is closer to transverse body plane). Abbreviations: DA, descending aorta; LPA, left pulmonary artery; PDA, patent ductus arteriosus; RPA, right pulmonary artery

But this condition can almost always be suspected as highly probable based on anatomic features. The probability of coarctation increases in the presence of hypoplasia of the transverse arch, relative distal displacement of the left subclavian, an indenting shelf on the greater curvature in the isthmus region and certainly hypoplasia of the isthmus.[2] Both branch pulmonary arteries should be defined and measured just distal to the origins.

The left to right shunt of a large PDA pulls blood during diastole in the aortic arch leading to an ambiguous spectral Doppler continuous flow velocity profile similar to that of coarctation of the aorta. Therefore, direct visualization of aortic arch and aortic isthmus in two-dimensional (2D) echocardiographic images can assure the absence of significant arch obstruction.

Normally, the ductus arteriosus originates from the aortic isthmus coursing anteriorly to the superior aspect of the left and main pulmonary artery (PA) junction. The PDA usually is narrowest at the pulmonary end and may have a wide ampulla where it joins the aorta. The ductal shelf projecting from the lesser curvature of the aortic arch, as a rule, does not obstruct flow. Although color flow mapping can guide the full course of the ductus, the 2D images give the optimal resolution for measuring the luminal diameter. If catheter-based closure is anticipated, measurements of the PDA, in a manner agreed on with the interventional cardiologist, can be usually obtained in imaging planes as shown in Figure 1A and B.

2.3 | Pressures and shunt physiology in ductal region

Spectral and color flow Doppler allow for analysis of hemodynamic effects of the PDA. Color flow of the PDA gives an initial rapid and useful survey of direction and velocity of flow. Then optimizing the angle of the ultrasound beam in line with the flow provides accurate spectral Doppler velocities. Various spectral Doppler patterns of PDA are demonstrated in Figure 2. Doppler patterns in the initial four days of life can predict the development of clinically significant PDA (the growing or pulsatile Doppler pattern can indicate a continuing risk of developing clinically significant PDA).[3] Bidirectional shunting with right to left shunt in systole and small left to right shunt in diastole suggests a "pulmonary hypertension" pattern[3] (Figure 2). In growing pattern[3] (Figure 2), the right to left shunt is only for a brief duration during systole and the left to right shunt increases. The pulsatile pattern[3] (Figure 2) has all left to right shunting with a low-peak velocity in systole and with the velocity decreasing rapidly in diastole (often to the baseline at end diastole). A moderate or large left to right shunt leads to a rapid near-equalization of the PA pressure to systemic pressure, the peak velocity is often <1.5 m/s and the PA pressure nearly equals the descending aorta pressure toward the end of diastole. A pure high velocity (often >2 m/s) continuous left to right shunt indicates that the PDA is generally small or has discrete narrowing (closing pattern[3]—Figure 2). Elevated pulmonary vascular resistance should be suspected when a PDA has low velocity left to right shunt and the left heart is not significantly enlarged. In a moderate to large PDA, a low velocity left to right shunt and low pulmonary vascular resistance are present when dilation of left heart, increased pulmonary venous or mitral inflow E wave flow velocity, holo-diastolic flow reversal at the descending aorta and prograde diastolic flow at the left pulmonary arteries are present. A systolic right to left shunting indicates elevated pulmonary vascular resistance which could be seen in persistent pulmonary hypertension but could also be seen as a part of transitional physiology in early postnatal life (especially when the shunt is brief). Pure right to left shunting indicates severe

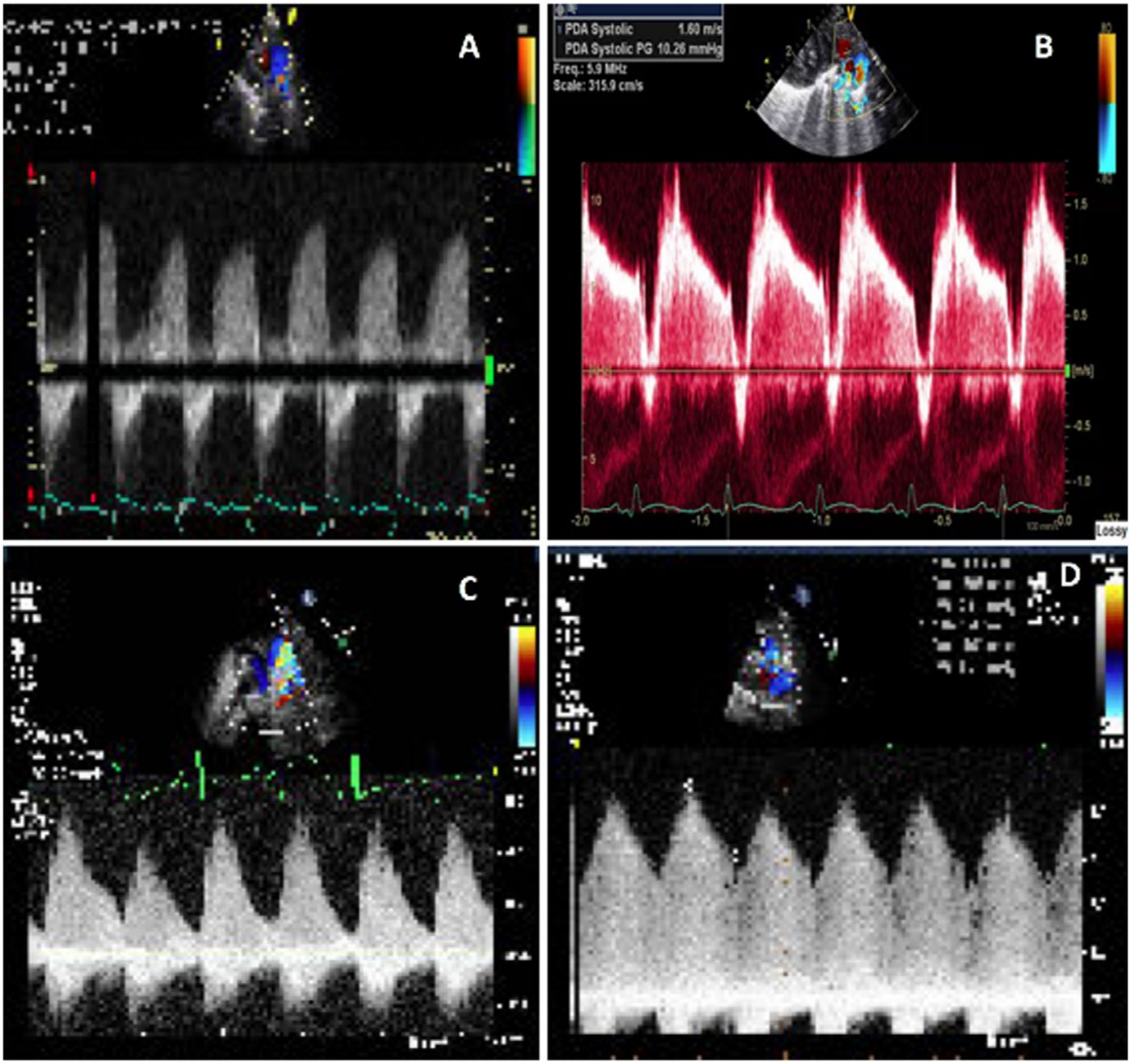

FIGURE 2 The various spectral Doppler patterns of PDA. (A) pulmonary hypertension pattern (B) growing pattern (C) pulsatile pattern (D) closing pattern. Abbreviation: PDA, patent ductus arteriosus

elevation of pulmonary vascular resistance. A moderate or large PDA limits the PA pressure from exceeding the descending aortic pressure thereby also limits the systolic right ventricular pressure. Restriction of PDA (in such cases with pure right to left shunting) could lead to elevation of RV pressure to supra-systemic level. The PDA closure is contraindicated in such scenario and pulmonary vasodilator therapy may be needed. Doppler evaluation of mesenteric vessels provides clues to the degree of systemic hypoperfusion. The ratio of celiac artery flow to left ventricular outflow tract flow was proposed as an indicator of systemic hypoperfusion and the cutoff value of 0.1 was established to separate hemodynamically significant PDA.[4]

2.4 | Intracardiac effects of the PDA

An increase in left to right ductal shunting should increase left atrial volume, but this trend gets mitigated by left to right shunting at foramen ovale or atrial septal defect if present. Linear measurement of left atrial to aortic root ratio (LA/AO) of at least 1.40 can discriminate clinically identified PDA patients from the controls.[5] But in the current era, we recognize its limitations. Katsuaki et al[6] have reported the left atrial volume indices may be superior to LA/AO. Biplane estimations of left atrial end systolic volume have not been validated relative to body metrics in premature infants but serve as an alternative to LA/AO for serial evaluation.

The left ventricle morphology gives insight in to the volume of left to right shunt, relative ventricular pressures and function. Serial increases in left ventricular dimensions correlate directly with the left to right shunting. These premature infants tend to have high heart rates, small structures, and often acoustic lung interference. This is why the excellent temporal resolution of M-mode can prove to be an advantage to 2D measurements. Echocardiographic assessment of diastolic function, in the presence of shunting and variable loading conditions, lacks reliability.

Right ventricular dimensions are usually provided qualitatively. Serial quantification of right ventricular systolic function can be provided in the four-chamber view by estimation of the fractional change in right ventricular area and base to apex shortening with tricuspid annular plane systolic excursion (TAPSE). The relative right ventricular pressure can be quantified by changes in the shape of the ventricular septum. The eccentricity index (EI) is a ratio of the two orthogonal diameters of the left ventricle in short axis. Normal RV pressure has an EI of 1. As RV pressure increases the diameter between the septum and posterior wall of the left ventricle decreases and so the index increases. From this projection, a "D"-shaped left ventricle implies equal pressures and an inverted septum is consistent with severe/supra-systemic pulmonary hypertension. Sharon et al[7] reported that more than half-systemic RV pressure became apparent at EIs ≥ 1.3. In a large PDA with severe pulmonary hypertension, the right to left shunt limits the RV pressure to near systemic levels and therefore the ventricular septum will flatten but not invert. Severely elevated pulmonary vascular resistance in the presence of luminal narrowing in the PDA will result in right ventricular systolic pressure exceeding aortic pressure with septal inversion and an EI ≥ 2. Continuous wave Doppler gradient of Tricuspid regurgitation, if present, can be useful in estimating the right ventricular systolic pressures. Although rare pulmonary veins stenosis should be ruled out in patients with elevated pulmonary vascular resistance.

3 | CONCLUSION

Management of the PDA in premature infants needs a collaborative effort between multiple disciplines. The echocardiogram plays a central role in the decision making. The anatomy of the PDA needs to be integrated with the use of color flow and spectral Doppler to understand the hemodynamic consequences on the pulmonary vasculature and the heart. It is important to estimate the relative size of the PDA and account for regional narrowing if present. The moderate to large PDA in presence of low pulmonary vascular resistance will show the left heart enlarging from the baseline obtained in the immediate newborn period and Doppler evidence of pulmonary steal of systemic blood flow. As pulmonary vascular resistance increases, the left to right shunt and pulmonary steal from the systemic circulation decreases, left heart volumes decrease, ventricular septum loses normal curvature and the EI increases. When the PDA is large, determining the status of the pulmonary vascular resistance is the single most important determinant of management. Multidisciplinary collaboration and use of reliable echo data are essential for risk stratification and decision making for the patients who live between the extremes of severely elevated and low pulmonary vascular resistance.

CONFLICT OF INTEREST

We have no financial relationship relevant to this article to disclose and we have no conflict of interest.

AUTHOR CONTRIBUTIONS

Prepared the main document, collected the echocardiographic images and prepared the figures, reviewed this writing with the senior author, submitted to the journal: Govinda Paudel. *Created the framework for the main document, reviewed and edited this article*: Vijaya Joshi.

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