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ORIGINAL PAPER

Hemodynamically Significant Patent Ducts Arteriosus: Impact of Ductal Size on Left Output and Aortic Doppler Velocimetry

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Abstract

Children with patent ductus arteriosus (PDA) present with several degrees of hemodynamic states. It is not known if there is any link between ductal size and hemodynamic states. This study elicited the prevalence of hemodynamically significant PDA (hsPDA) and attempted to document the impact of ductal size on left output and aortic Doppler velocimetry. This is a cross-sectional study that assessed the prevalence of hsPDA and the relationship of ductal size and parameters of left ventricular function (LVF) in children and adolescents aged 3–19 years. The mean left ventricular mass (LVM) for respondents with PDA, 8.3 ± 5.3, was lower than that of the control, 14.3 ± 5.2, and the mean difference was found to be statistically significant (Mann–Whitney $U = 7.270$, $p < 0.001$). The prevalence of small, moderate, and large hsPDA was 40.7%, 35.6%, and 23.7% respectively. The commonest age of presentation of hsPDA is 1 month of age. There was a weak negative correlation between PDA size and ejection fraction (EF), increases in PDA size correlate with decreases in EF, but this was not found to be statistically significant ($n = 59$, $r = -0.233$, $p = 0.076$). There was a weak positive correlation between PDA size and velocity, increases in PDA size correlate with increases in velocity, and this was not found to be statistically significant ($n = 43$, $r = 0.252$, $p = 0.104$). The prevalence of hsPDA in this study was high. The LVM in healthy children and adolescents was higher than in those with PDA. Left ventricular mass in children with PDA correlates inversely with descending aorta velocity.

Keywords LVM · Ductal size · LV function · PDA · Control

Abbreviations

IVSd	Inter ventricular septum diameter in diastole
LVIDd	Left ventricular internal diameter in diastole
LVPWd	Left ventricular posterior wall diameter in diastole
IVSs	Inter ventricular septum diameter in systole
LVIDs	Left ventricular internal diameter in systole
EF	Ejection fraction
FS	Fractionating shortening
LV mass	Left ventricular mass

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Introduction

The patent ductus arteriosus (PDA) is a vascular tissue that connects the proximal descending aorta to the left pulmonary artery juxta-position to the subclavian artery [1]. The ductus arteriosus usually obliterates at birth and gets closed after the first days of life [2]. Persistence of a PDA is one of the commonest congenital heart diseases that causes left-to-right shunt. Left ventricular mass in children with PDA also plays a role in predicting hsPDA. PDA is essential for fetal life [3]. The persistence of a PDA may increase the risk of morbidity in the very preterm. This includes intraventricular

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hemorrhage (IVH), necrotizing enterocolitis (NEC), and chronic lung disease (CLD) [4]. This usually occurs if the PDA is a hsPDA. There is no clear and generally acceptable definition of hsPDA [4]. There are echocardiographic indices that may be used to determine which PDA is hemodynamically significant. Echocardiography could help to elicit the magnitude of shunt volume. It can also be used to determine the hemodynamic significance of PDA. This includes the hemodynamic impact from systemic hypo-perfusion and pulmonary over-circulation due to shunt volume [5–7]. Various echocardiographic indices have been used in staging or scoring hsPDA. This has been of significance in surgical decision-making [8].

Currently, the definition of hsPDA is controversial as it is entirely based on size. For instance, a transductal diameter of > 1.5 mm is taken as significant based on the fact that at this cut-off, there is hypo-perfusion of the end organ [9]. However, the cut-off point of 1.5 mm is limited since it does not take into account parameters such as patient size or development [10]. For example, the clinical correlates of an asymptomatic 32-week infant with PDA measuring 3.0 mm differ significantly from a ductus of comparable size on the second day of life in a 24-week infant with respiratory failure [10].

It is also important to note certain co-founders such as gestational or chronological as important predictors of hsPDA [11]. Notwithstanding, hsPDA is simply defined when the PDA is PDA ≥ 1.5 mm, with a flow reversal in the descending aorta, a left atrial-to-aortic root ratio ≥ 1.5, and paucity of end-diastolic flow in the descending aorta [12].

Clinical sequel of hsPDA is not without increased morbidity and mortality in newborns [12]. The clinical features of hsPDA depend on the level and severity of the shunt volume across the ductus arteriosus [12]. This also depends on the pulmonary and systemic vascular resistance and the ductal size [13]. Infants with a large PDA usually have no clinical signs in the first 4–6 weeks of life due to persistently high pulmonary vascular resistance (PVR) with an attendant decreased amount of PDA shunt volume [13]. However, when PVR falls, shunt volume increases, and the infant now presents with signs and symptoms of PDA. These include features of dyspnoea on exertion, poor weight gain, and a machinery murmur [13]. With time, hyperactive precordium, widened pulse pressure, and collapsing pulses ensue [14]. If there were no appropriate adaptive mechanisms to the increased shunt volume, signs of heart failure occur [15, 16].

The prevalence of PDA ranges from 5 to 10% with very high mortality, especially in the preterm [17]. The hemodynamically significant types always cause flow reversal in the descending aorta, valvular regurgitation, chamber dilatation, pulmonary hypertension, and alteration of ventricular function [18]. The effects of organ blood flow, the impact of hsPDA on the newborn, and its effects on necrotizing enterocolitis and prematurity depend so much on the size of the PDA [19]. The use of the size of PDA to predict the hemodynamic effects of PDA on left ventricular function and descending aorta blood flow will help the clinician to decide management protocols for such patients based on both echocardiogram findings and clinical symptoms. Studies have not shown clearly if the size of the internal diameter of the narrowest portion of PDA predicts shunt flow, though small PDAs have been shown not to affect any shunt reversal or ventricular function. This may not be said for larger sizes. It is also important to note that ductal size is known to affect the magnitude of the left-to-right shunt with eventual disturbance of the peripheral vascular resistance (PVR)-to-systemic vascular resistance (SVR) ratio [20, 21]. The causal effects of PDA in the very preterm and in children are related to abnormal descending aorta velocimetry. For instance, Broadhouse et al. [21] among 29 children with PDA and controls noted that though there is no significant difference in ejection fraction and fractional thickening between subjects and control, a significant association was seen between left ventricular mass and shunt volume and ejection fraction [22].

Studies that assess the impact of size on descending aorta velocimetry and the impact of size on left ventricular function in children with PDAs are very rare. Literature has also shown little or no studies on the impact of left ventricular mass on descending aorta blood flow. This work will help the clinician in managing children with PDA, in risk stratification and prognostication. The study seeks to elicit if there is any relationship between the size of PDA with any of the hemodynamically significant parameters of PDA such as descending aorta blood flow and left ventricular function. It also seeks to compare the impact of LVM on descending aorta velocimetry. The study seeks to determine the prevalence of hsPDA among children with PDA.

Methods

Study Design

This is a cross-sectional study that assessed the prevalence of hsPDA and the relationship of ductal size and parameters of left ventricular function in children and adolescents aged 3–19 years.

Study Area

This study was carried out in three referral hospitals in Enugu Metropolis. These hospitals are referral centers for children with congenital cardiac defects.

Study Population

Children and adolescents with patent ductus arteriosus confirmed by echocardiography and who were aged 3–19 years were recruited in this study. The control population was children with no structural or acquired heart disease and who were healthy.

Inclusion Criteria

Children and adolescents with PDA confirmed by echocardiography and who were aged 3–19 years and healthy controls matched for gender and age were included in the study.

Exclusion Criteria

Children whose parents did not grant any form of consent, preterm babies, and those children who did not give assent to participating in the study were excluded from the study.

Case Selection

Children who presented with PDA and their controls who met the inclusion criteria were consecutively recruited into the study.

Study Instrument

Echocardiography models namely the E2-model Sonoscape Medical Corp 2019 Cardiac Ultrasound Imaging and the Versana Premier 2019 Cardiac Ultrasound Imaging from the hospital of study were used for PDA imaging. The best view used to study hsPDA is the parasternal short axis view and the suprasternal view (HSAX) otherwise called the ductal view [23–25]. The ductus arteriosus is seen clearly from the base of the heart when the probe is tilted anteriorly toward the pulmonary artery [25]. This image is enhanced using a pulsed wave and color Doppler. The descending aorta and the left pulmonary artery were viewed using the suprasternal axis view [25]. We ruled out any isomerism or heterotaxy syndrome that may be associated with PDA using the sub-costal view [25]. The ductal size was measured using the high left parasternal short axis [25]. The narrowest point of the ductus arteriosus was measured before it joins the main pulmonary artery [23–25]. Left-to-right flow was documented as a continuous flow during systole and diastole. The left ventricular function was measured with the aid of an M-mode echocardiograph. The M-mode cursor is aligned at the tip of mitral leaflets and passes through the middle of the LV cavity. This gave an M-mode trace [25].

Echocardiographic Determination of the Descending Aorta Velocity

The descending aorta velocity was assessed in a suprasternal long-axis view with a continuous wave Doppler ultrasound, and every obstruction or regurgitation was ruled out [26].

Classification of Ductal Size Based on Hemodynamic Significance

This was classified as asymptomatic when there is no evidence of ductal flow on Doppler echocardiography, and small, non-hsPDA occurs when the transductal diameter of PDA is less than 1.5 mm with a descending aorta velocity of more than 2.0 m/s and no signs of left heart dilatation and very minor left-to-right shunt [27, 28]. Moderate hsPDA is classified as when the measurement falls between 1.5 and 3 mm, with non-restrictive pulsatile transductal flow of < 2.0 m/s with mild-moderate left heart dilatation. hsPDA is large when the ductal size is more than 3 mm with an obvious left-to-right shunt evidenced by a continuous flow during systole and diastole and severe left heart dilatation [27, 28].

Left Ventricular Output

This term includes all parameters of LVF.

Aortic Doppler Velocimetry

This is defined as the rate of blood per unit second across the descending aorta.

Data Analysis

Data entry and analysis were done using International Business Machine, Statistical Product for Service Solutions (IBM-SPSS) statistical software version 25. Categorical variables were presented using frequencies and proportions, while continuous variables were summarized using mean and standard deviation. Student *t*-test was used to compare the mean difference between the two groups, and where appropriate, Mann–Whitney *U* test was applied. When the comparison involved more than two groups, an analysis of variance was utilized. Chi-square test of statistical significance was used to compare the difference in proportions between two categorical variables. Correlation analysis was used to compare the strength of the linear relationship between two continuous variables. In all these applications, the level of statistical significance was determined by a p-value of < 0.05.

Results

Table 1 shows the characteristics of the respondents. The mean age of respondents with PDA, 1.1 ± 2.9, is the same as that of the control, 1.1 ± 2.9. The PDA group and control had an equal proportion of female respondents, 63.0% (Fisher's exact, $p = 1.0$).

Table 2 shows that the mean LVM for respondents with PDA, 8.3 ± 5.3, was lower than that of the control, 14.3 ± 5.2, and the mean difference was found to be statistically significant (Mann–Whitney $U = 7.270$, $p < 0.001$). The mean LVIDd of the control, 29.8 ± 12.3, was significantly higher than that of those with PDA, 18.3 ± 9.6, and the mean difference was found to be statistically significant (Student $t = 6.632$, $p < 0.001$). The mean LVPWs of the control, 7.9 ± 3.5, was significantly higher than that of those with PDA, 4.4 ± 2.2 (Student $t = 7.655$, $p < 0.001$). The mean FS of respondents with PDA, 40.9 ± 15.6, was higher than that of the control, 36.5 ± 8.4, and the mean difference was found to be statistically significant (Student $t = 2.202$, $p = 0.029$). The mean velocity of respondents with PDA, 2.0 ± 0.9, was significantly higher than that of the control, 1.3 ± 0.2 (Student $t = 5.720$, $p < 0.001$) (Table 2).

Table 3 shows the classification of PDA. The highest proportion of the respondents who had PDA, 40.7%, had small PDA, while the least proportion, 23.7%, had large PDA. The prevalence of small, moderate, and large hsPDA was 40.7%, 35.6%, and 23.7%, respectively. Using retrograde flow across the descending aorta and a velocity of more than 2 m/s, the prevalence of hsPDA was 18/59 (30.5%). The commonest age of presentation of hsPDA is 1 month of age. Females have the highest proportion of hsPDA with a female-to-male ratio of 4:1.

Table 4 shows that the respondents with small PDA had the highest mean EF, 71.9 ± 9.5, while those with large PDA

Table 1 Characteristics of the subjects and control

Variable	PDA ($n = 81$)	Control ($n = 81$)		
Age of respondents in years				
Mean ± SD	1.1 ± 2.9	1.1 ± 2.9	0.0	1.0
Gender				
Male	30 (37.0)	30 (37.0)	FT	1.0
Female	61 (63.0)	61 (63.0)		

FT Fisher's exact test

Table 2 Comparison of parameters between those with PDA and control

Variable	PDA ($n = 81$)	Control ($n = 81$)	Student t	p-value
Weight	9	77		
Mean ± SD	3.0 ± 1.1	22.1 ± 22.3	7.453*	< 0.001
LVEDD	81	81		
Mean ± SD	27.2 ± 13.6	44.1 ± 16.4	7.116	< 0.001
LVM	81	81		
Mean ± SD	8.3 ± 5.3	14.3 ± 5.2	7.270*	< 0.001
LVIDd	81	81		
Mean ± SD	18.3 ± 9.6	29.8 ± 12.3	6.632	< 0.001
LVPWd	81	81		
Mean ± SD	4.4 ± 4.3	5.9 ± 2.2	2.753*	0.007
IVSs	81	81		
Mean ± SD	4.6 ± 3.7	8.5 ± 3.4	7.004*	< 0.001
LVIDs	81	81		
Mean ± SD	11.7 ± 5.7	19.4 ± 8.0	7.019	< 0.001
LVPWs	81	81		
Mean ± SD	4.4 ± 2.2	7.9 ± 3.5	7.655	< 0.001
EF	81	81		
Mean ± SD	64.9 ± 14.7	66.8 ± 9.7	0.960	0.339
FS	81	81		
Mean ± SD	40.9 ± 15.6	36.5 ± 8.4	2.202	0.029
Velocity	54	76		
Mean ± SD	2.0 ± 0.9	1.3 ± 0.2	5.720	< 0.001

*Mann–Whitney U

Table 3 Relative frequencies of PDA size

Variable	Frequency ($n = 59$)	Percent (%)
Classification of PDA		
Small	24	40.7
Moderate	21	35.6
Large	14	23.7

Table 4 Comparison of ductal size and left ventricular function parameters

Variable	Sample size	Mean ± SD	F	p-value
EF				
Small PDA	($n = 24$)	71.9 ± 9.5	4.165	0.021
Moderate PDA	($n = 21$)	65.2 ± 8.3		
Large PDA	($n = 14$)	61.1 ± 17.8		
FS				
Small PDA	($n = 24$)	40.3 ± 11.9	1.779	0.178
Moderate PDA	($n = 21$)	33.6 ± 5.7		
Large PDA	($n = 14$)	37.5 ± 17.8		
Velocity				
Small PDA	($n = 16$)	2.0 ± 0.7	1.038	0.363
Moderate PDA	($n = 18$)	1.8 ± 0.9		
Large PDA	($n = 9$)	2.3 ± 0.8		

had the least, 61.1 ± 17.8, and the mean difference was found to be statistically significant ($F = 4.165$, $p = 0.021$).

Table 5 shows that there was a very weak positive correlation between PDA size and LVM, increases in PDA size correlate with increases in LVM, but this was not found to be statistically significant ($n = 59$, $r = 0.192$, $p = 0.146$). There was a weak negative correlation between PDA size and EF, increases in PDA size correlate with decreases in EF, but this was not found to be statistically significant ($n = 59$, $r = -0.233$, $p = 0.076$). There was a weak positive correlation between PDA size and velocity, increases in PDA size correlate with increases in velocity, and this was not found to be statistically significant ($n = 43$, $r = 0.252$, $p = 0.104$).

Table 6 shows that the mean PDA size for males, 5.0 ± 2.4, was higher than that of the females, 4.3 ± 2.2, but the mean difference was not found to be statistically significant (Student $t = 1.097$, $p = 0.277$). The mean EF for females, 66.1 ± 14.3, was higher than that of males, 62.9 ± 15.6, but the mean difference was not found to be statistically significant (Student $t = 0.916$, $p = 0.362$). The mean FS score for male, 40.3 ± 15.1, and female respondents, 41.2 ± 16.0, was comparable (Student $t = 0.250$, $p = 0.803$).

Table 5 Correlation of ductal size with left ventricular function parameters

Variable	Sample size (n)	Correlation coefficient r	p-value
Correlation of PDA size with			
Age	($n = 59$)	0.069	0.606
LVM	($n = 59$)	0.192	0.146
EF	($n = 59$)	−0.233	0.076
FS	($n = 59$)	0.056	0.676
Velocity	($n = 43$)	0.252	0.104

Table 6 Gender comparison of left ventricular function parameters

Variable	Male ($n = 20$)	Female ($n = 39$)	Student t	p-value
PDA size				
Mean ± SD	5.0 ± 2.4	4.3 ± 2.1	1.097	0.277
LVM	($n = 30$)	($n = 51$)		
Mean ± SD	9.8 ± 5.5	7.4 ± 5.1	1.988*	0.050
EF				
Mean ± SD	62.9 ± 15.6	66.1 ± 14.3	0.916	0.362
FS				
Mean ± SD	40.3 ± 15.1	41.2 ± 16.0	0.250	0.803
Velocity	($n = 19$)	($n = 35$)		
Mean ± SD	1.7 ± 0.6	2.1 ± 1.0	1.570	0.122

*Mann–Whitney U test

Table 7 Correlation between LVM and descending aorta blood flow

Variable	Sample size (n)	Correlation coefficient	p-value
Correlation of LVM and			
Velocity	($n = 54$)	−0.174	0.209
Age	($n = 81$)	0.318	0.004

Table 7 shows a very weak negative correlation between LVM and descending aorta velocity, increases in LVM correlate with increases in velocity, but this was not found to be statistically significant ($n = 54$, $r = -0.174$, $p = 0.209$). There was a weak positive correlation between LVM and age, increases in age correlate with increases in LVM, and this was found to be statistically significant ($n = 81$, $r = 0.318$, $p = 0.004$).

Discussion

This study aimed to ascertain the relationship between the size of PDA on left ventricular function and the descending aorta velocity. It also compared various parameters of the left ventricular function of children with PDA and healthy children. This study also elicited the prevalence of hsPDA and attempted to document associated factors. The prevalence of small, moderate, and large hsPDA seen in this study was 40.7%, 35.6%, and 23.7%, respectively. Using retrograde flow across the descending aorta and a velocity of more than 2 m/s, the prevalence value of 18/59 (30.5%) was documented. The prevalence values have clinical implications as they can be used for prognostication, triaging, and clinical and surgical decision-making. The high prevalence could also serve as a guide to the clinician on the need for appropriate case selection and early referral of cases of hsPDA.

Michelle [29] et al. noted a prevalence of hsPDA among 38 infants with PDA, 52.6% with 11 infants showing evidence of retrograde diastolic blood flow in the descending aorta. The challenge in assessing hsPDA using echocardiography is the obvious variability in the definition of hsPDA [30]. There is no standard consensus on what parameters constitute a hsPDA [21]. Some authors have proposed the use of clinical and echocardiographic criteria to define hsPDA; nevertheless, there is disagreement on what should be the cut-off values [31]. Furthermore, Shepherd et al. [32] have included gestational age as a very vital criterion in the definition of hsPDAs [31].

hsPDA was seen mainly in neonates and among female folks as documented in this study. The neonatal predominance seen in this study will help the clinician to have a

very high index of suspicion of possibilities of complications arising from hsPDA and may also help the surgeon to take appropriate measures especially when handling neonates with PDA who have hemodynamic changes.

This finding is also corroborated by other authors [32, 33]. Furthermore, increased cardiac output and lung overload which are surrogate markers of pulmonary hypertension, coupled with aortic runoff seen in neonates and younger children, could also explain this phenomenon [34]. In addition, the female preponderance for hsPDA noted in this study may be explained by a similar reason for the increasing frequency of females with pulmonary hypertension. Factors such as genetic mutation in the morphogenetic protein 2 (BMPR2) gene, mutational changes in the BMPR2 receptor, estrogen signaling, and differences in the immune system have all been implicated [35–44].

This study has shown that an increase in PDA size correlates with a decrease in ejection fraction (EF), while increases in PDA size correlate with an increase in the descending aorta velocity. The increase of ductal size with velocity may be explained possibly by an increased left-to-right shunt, left chamber dilatation, valvular regurgitation, increased cardiac output, and pulsatile flow from the aorta to the left pulmonary artery which are all size-dependent [45–48].

Hsu et al. [49] noted, using echocardiography and Doppler assessments, that the size of PDA increases the risk of abnormal organ blood flow, and there is an inverse relationship between PDA size and the mean velocity of descending aorta blood. The study population in the above study was preterm. Conversely, the inverse relation noted between ductal size and left ventricular function could also be explained by the fact that hemodynamic sequel from increased ductal size results in increased left atrial-to-aortic root ratio, increased left heart dilatation, and resultant left ventricular dysfunction. However, Shimada et al. [50] noted that infants with hsPDA had a significantly higher LVF and lower blood flow in the abdominal aorta compared with controls. The small sample size used by the latter may explain these variations.

We noted an inverse relationship between left ventricular mass and descending aorta velocity. This inverse correlation between LVM and descending aorta velocity could be explained by the alteration of the arterial-ventricular interaction. Nevertheless, a study noted a positive correlation between blood flow in the descending aorta and LVM [51]. The study above differs from this current study because the former focused on children with coarctation of the aorta, while the latter was on children with PDA [52].

Left ventricular mass in children with PDA was noted to be lower compared with age and gender-matched controls. Besides, LVM is a function of interventricular septum diameter in diastole (LVIDD), left ventricular internal diameter in systole (LVIDS), and interventricular septum diameter in systole (IVSS). These values in children with PDA were lower than that of normal children as seen in this study. The increased left ventricular dilatation may explain the reduced LVM seen in the subjects with PDA. Several searches in the literature showed no work that compares LVM in children with PDA with healthy individuals. However, Jeong et al. [53] noted significant differences in left atrial dilatation, LVEDD, LVEF, and FS after catheter closure of children with PDA compared with those before catheter closure. They noted that these indices were significantly lower in children with PDA who had catheter closure than subjects who had no catheter closure, signifying that PDA closure results in transient abnormal cardiac function in children [53]. This finding could be of clinical significance in grading severity to screen those with a risk of pulmonary hypertension and to start early treatment to avert compaction and to reduce morbidity and mortality that arose from the disease.

The high LVM seen in males could be due to gender differences in myocardial mass and the number of myocytes during embryogenesis. Besides, a higher tendency of hypertension in males may also explain the increased LVM seen among them.

Children with PDA had higher FS and left ventricular ejection fraction (LVEF) when compared with healthy children. This could be explained by the fact that the left-to-right shunt in hsPDA is volume-dependent which also depends on the size of the PDA. However, small-sized PDAs may not immediately affect the LVEF or EF due to the low shunt volume [54]. However, over time, irrespective of the size of the PDA, the overload may increasingly result in pulmonary overload, increased pulmonary vascular resistance, and resultant failure of the left ventricular chamber [55–58].

The descending aorta blood flow in children with PDA was quite higher than control. This could simply be explained by several factors such as shunt defects, hemodynamic changes created from the left-to-right shunt, and chamber dilatation seen in children with PDA which is absent in healthy children.

Conclusion

The prevalence of hsPDA in this study was high. The LVM in healthy children and adolescents was higher than in those with PDA. LVM in children with PDA correlates inversely with descending aorta velocity. An increase in PDA size correlates with a decrease in EF, while an increase in PDA size correlates with an increase in descending aorta velocity.

Limitations

Concerns about the definition of hsPDA may have affected the prevalence value obtained in this study. An international consensus is needed as this will help clinicians and surgeons know the point at which to intervene. We could not use the cardiac catheterization (a definitive measure of pulmonary vascular resistance in PDA) procedure in estimating the hemodynamic effects of PDA due to the unavailability of facility, cost, and personnel.

Area of Future Studies

It is expedient to devise a generally acceptable risk score for hsPDA from prospective observation of cohort studies and the subjects followed over time. Furthermore, a routine and an elaborate echocardiogram should be performed on the first and third day of life to screen for markers of pulmonary hypertension and left ventricular (LV) diastolic function.[59] Finally, in the near future, definite clinical characteristics should be developed [59]. This may be used to devise a PDA severity score (PDAsc) to predict chronic lung disease [59].

At the same time, since congenital heart disease (CHD) in children and adolescents is highly linked to maternal lifestyle, we should conduct positively the E(e)SEEDi healthy lifestyle [60, 60] for prevention of CHD including PDA.

Clinical Implication

Though children with PDA may have normal EF and LVEF, however, monitoring their LVM and aortic blood flow is crucial both before and after surgery. This may help to avert some morbidity later in life. Children with large hsPDA should have a catheter closure at the earliest to avert the numerous complications that follow such a defect.

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Author Contribution CJM conceived and designed this study, while CJM, OEN, CAT, and OJT helped in the critical revision of the article. CJM and OEN also did the data analysis/interpretation. All authors have read and approved the manuscript.

Data Availability Data are however available from the authors upon reasonable request and with permission of the corresponding Author.

Code Availability Code for data cleaning and analysis as well as software application or custom code will be provided as part of the replication package after acceptance of the work.

Declarations

Ethical Approval The approval of the Health Research Ethics Committee of the University of Nigeria Teaching Hospital, Enugu was obtained.

Consent for Publication This was fulfilled since it was a criterion for ethical clearance to be granted.

Conflicts of Interest The authors declare no competing interests.

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