

Assessment Of Immediate and Short-Term Changes in Left Ventricular Systolic Function After Interventional Patent Ductus Arteriosus (PDA) Closure by Transthoracic Conventional Echocardiography and Tissue Doppler

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ABSTRACT

Background: Failure of the ductus arteriosus to close naturally within 24 – 48 hours post naturally usually results into significant hemodynamic compromise that necessitates its early closure either interventional or surgically.

Aim: To assess the left ventricular (LV) dimensions and systolic function within the first week and three months after interventional PDA closure.

Patients and methods: Infants and children (6month -12years) undergoing transcatheter PDA closure. Pre closure and catheter data were collected and a comprehensive transthoracic echocardiography utilizing two-dimensional (2D) and Tissue doppler Imaging (TDI) has been performed within the first week and 3 months post closure.

Results: 30 patients who underwent catheterization closure of PDA consisting of 22 females (73%) and 8 males (27%) were assessed. Although pre-closure 2D assessment did not show any LV systolic dysfunction, our first echo post closure documented 4 (13%) patients with LV systolic dysfunction as well as 3 (10%) patients with right ventricular (RV) systolic dysfunction using two-dimensional imaging. Using TDI 16 (53%) patients had RV diastolic dysfunction of whom 10 (33%) patients had LV diastolic dysfunction where 3 patients had improved LV diastolic function over follow up.

Conclusion: Study shows 13.3% of patients develop transient LV systolic dysfunction post-PDA catheter closure (75% resolve by 3month), with 53% having Right RV diastolic dysfunction, necessitating TDI follow-up.

Keywords: Pediatric, PDA, Cardiac function, Transcatheter closure

1. INTRODUCTION

Patent Ductus Arteriosus (PDA) is a frequently observed acyanotic congenital cardiac illness resulting from the failure of physiological constriction of ductus in neonates. The occurrence of patent ductus arteriosus as a congenital cardiac defect is around eleven percent. The isolated PDA is present in 1 in 2000 live term births. While other treatments exist for PDA, the most successful and safe approach is percutaneous closure with a ductal occluder (1).

A significant left-to-right shunt causes left ventricular volume overload and remodeling, leading to changes in the systolic and diastolic functions of both the left and right ventricles. In most cases, these alterations often revert following PDA device closure, except in a few that have left ventricular systolic dysfunction (2,3,4).

LV systolic dysfunction was documented in 14.4% post PDA closure, with significant reduction in fractional shortening (FS) immediately post-procedure that recovered over 3 months as documented in a recent study (5).

Published literature has scant information regarding left ventricular diastolic dysfunction and influence on right ventricular (RV) functions hasn't been examined well as mainly 2D imaging was the mode of choice alone rather than being coupled with TDI. Therefore, this prospective research with a sizable cohort was undertaken to evaluate alteration in RV and LV diastolic and systolic functions following percutaneous device closure of patent ductus arteriosus with proper monitoring (6).

Aim of this research was to measure left ventricular dimensions and systolic function after interventional PDA closure.

1. Patients and methods

This was Longitudinal research which involved 30 Pediatric cases of both genders who underwent interventional catheter closure of Isolated PDA between the age of 6 months and 12 years without severe pulmonary hypertension, congenital heart & systemic diseases.

Ethical consideration: This research has been submitted to the Institutional Review Board [IRB] of the Faculty of Medicine, 6th of October University, for its ethical approval (SCCREIRB-MEDICIN6OCT-PU-001-121224-018). Informed consent will be obtained from the parents of each participant.

Methods: Beside personal and clinical data, Echocardiographic evaluation has been conducted utilizing conventional and tissue Doppler imaging (TDI) techniques. Pre catheter Echo data were collected from archive as well as catheterization data. On both follow up echo LV dimensions including Left ventricular end systolic dimension (LVESD), left ventricular end diastolic dimension (LVEDD), aorta (Ao), left atrium (LA) and LA/Ao ratio as well as systolic function including fractional shortening (FS) and ejection fraction (EF) and Mitral Annular Plane Systolic Excursion (MAPSE) along with RV systolic function using Tricuspid Annular Plane Systolic Excursion (TAPSE) was assessed using 2D Imaging (M Mode). TDI has been utilized to measure diastolic function in both LV and RV measuring systolic velocity (S'), early diastolic velocity (E'), E/E' (conventional/tissue doppler), Atrial contraction velocity (A') & Myocardial Performance Index (MPI).

Statistical analysis:

The data were input into the computer and analyzed utilizing IBM SPSS software version 20.0 (Armonk, NY: IBM Corp, released in 2011). Qualitative data have been described utilizing percent and number. The Shapiro-Wilk test has been utilized to assess the normality of the distribution. Quantitative data were characterized by range (maximum and minimum), mean, median, standard deviation, and interquartile range (IQR). The significance of the outcomes obtained was assessed at the five percent level. The P value will be deemed statistically significant if p-value under 0.05.

2. Results

Patient Characteristics and Anthropometric Measurements:

Our sample consisted of 22 females (73%) and 8 males (27%). The patients' median age at the time of the procedure was 19.5 months ranging from 6 to 108 months. Regarding growth measurements, the average weight was 9.95 kg ranging from 8.5 to 17 kg, and the average height was 85.60 ± 20.71 cm with a mean body mass index (BMI) of 17.25 ± 3.07 kg/m² as illustrated in **table (1)**.

Table (1): Descriptive analysis of the cases examined according to demographic and anthropometric measurement

	Min. – Max.	Mean ± SD.	Median (IQR)
Age (months)	6.0 – 108.0	-	19.50 (9.0 – 69.0)
Weight (kg)	5.80 – 32.0	-	9.95 (8.50 – 17.0)
Height (cm)	58.0 – 122.0	85.60 ± 20.71	-
BMI (kg/m²)	11.45 – 24.35	17.25 ± 3.07	-

IQR: Inter quartile range

SD: Standard deviation

Table (2): Catheterization data and analysis

	No.	%
PDA Shape		
Conical	23	76
Tubular	2	6
Flask	5	16
Pulmonary end (mm) Mean ± SD	2.60 ± 0.93	
Min. – Max.	1.0 – 4.70	
Aortic end (mm) Mean ± SD	6.76 ± 2.16	
Min. – Max.	1.50 – 11.0	
Length (mm) Mean ± SD	6.67 ± 0.82	
Radiation Dose (μGy·m²)		
Min. – Max.	9.60 – 715.0	
Median (IQR)	72.0 (41.0 – 152.0)	
Radiation Time (minutes)		
Min. – Max.	5.0 – 63.0	
Median (IQR)	11.50 (8.40 – 22.0)	

As shown in **table (2)**, most PDAs about 23 cases had a conical shape (76%) However, the flask-shaped (16%) and tubular (6%) morphologies were less common. During our procedures, the radiation dose ranged between 41 and 152 with a median of 72 μGy·m². The median radiation time was 11.5 minutes with a minimum of 8.4 and a maximum of 22. The mean PDA length was 6.67 mm (± 0.82) with a mean pulmonary end of 2.6 mm (± 0.93) and mean aortic end of 6.76 mm (± 2.16).

Table (3): Comparative analysis between the three examined periods with regard to m-mode Echocardiographic parameters.

	Pre		1 st post		2 nd post		p
	No.	%	No.	%	No.	%	
LVEDD							0.673
Min. – Max.	22.0 – 40.0		22.0 – 38.0		23.0 – 39.0		
Mean ± SD.	30.73 ± 4.79		31.0 ± 4.39		30.57 ± 4.18		
Z-Score							
Normal	11	57.9	25	83.3	25	83.3	
Abnormal (>2)	6	31.6	4	13.3	2	6.7	
Abnormal (<-2)	2	10.5	1	3.3	3	10.0	
Min. – Max.	-2.49 – 4.39		-2.20 – 3.14		-3.40 – 3.60		0.658
Median (IQR)	0.46 (-0.80 – 2.40)		0.37 (-0.69 – 1.10)		0.22 (-1.39 – 1.0)		
LVESD							0.254
Min. – Max.	12.0 – 26.0		13.0 – 26.0		13.0 – 26.0		
Mean ± SD.	19.05 ± 3.38		20.27 ± 3.36		19.27 ± 3.19		
Z-Score							
Normal	11	73.3	26	86.7	24	80.0	
Abnormal (>2)	2	13.3	4	13.3	4	13.3	
Abnormal (<-2)	2	13.3	0	0.0	2	6.7	
Min. – Max.	-3.0 – 3.58		-1.45 – 4.64		-3.50 – 3.70		0.164
Median (IQR)	-0.31 (-0.95 – 1.45)		0.31 (-0.64 – 1.46)		-0.34 (-1.0 – 1.04)		
EF							0.001*
Min. – Max.	65.0 – 77.0		52.0 – 78.0		59.0 – 77.0		
Mean ± SD.	70.90 ± 3.86		64.90 ± 5.79		67.93 ± 5.62		
Sig.bet. periods	p ₁ =0.005*, p ₂ =0.160, p ₃ =0.103						
FS							<0.001*
Min. – Max.	34.0 – 45.0		26.0 – 46.0		30.0 – 44.0		
Mean ± SD.	38.25 ± 2.94		34.47 ± 4.16		36.77 ± 4.10		
Sig.bet. periods	p ₁ =0.002*, p ₂ =0.188, p ₃ =0.035*						
Z-Score							
Normal	23	95.8	23	76.7	25	83.3	
Abnormal (>2)	1	4.2	3	10.0	4	13.3	
Abnormal (<-2)	0	0.0	4	13.3	1	3.3	
Min. – Max.	-1.0 – 2.40		-3.80 – 4.0		-2.50 – 4.0		0.006*
Median (IQR)	0.07 (-0.38 – 0.81)		-0.15 (-1.30 – 0.50)		0.20 (-0.40 – 0.84)		
Sig.bet. periods	p ₁ =0.001*, p ₂ =0.248, p ₃ =0.043*						
LA/Ao							0.033*
Min. – Max.	1.10 – 2.0		1.0 – 1.86		0.94 – 1.60		
Mean ± SD.	1.43 ± 0.26		1.38 ± 0.26		1.27 ± 0.17		

IQR: Inter quartile range; SD: Standard deviation

F: F test (ANOVA) with repeated measures, Sig. bet. periods were done using Post Hoc Test (adjusted Bonferroni)

Fr: Friedman test, Sig. bet. periods were done using Post Hoc Test (Dunn's)

p: p value for comparing between the studied periods

p1: p value for comparing between pre and 1st post

p2: p value for comparing between pre and 2nd post

p3: p value for comparing between 1st post and 2nd post

*: Statistically significant at p-value not more than 0.05

As shown in **table (3)** LV Dimensions: LVEDD dilation (Z-score > +2) was present in 6 patients' pre-intervention, improved to 4 at the 1st echo and persisted in only 2 at the 2nd echo. Mean LVEDD and LVESD values showed no statistically significant changes across all time points. LA/Ao ratio significantly reduced from 1.43 ± 0.26 to 1.27 ± 0.17 (p = 0.033). LV Systolic Function: FS significantly declined from 38.25% to 34.47% (p < 0.001), and EF from 70.90% to 64.90% (p = 0.001) post-intervention. LV systolic dysfunction (FS Z-score < -2) was documented in 4 patients (13.3%) at 1st echo; 3 recovered by follow-up, leaving 1 patient (3.3%) with ongoing dysfunction also MAPSE improved from a median of 9 mm to 10 mm but without statistical significance. Initially, 4 patients had low MAPSE Z-scores; only 1 remained abnormal at follow-up.

Table (4): Comparison between 1st post and 2nd post according to LV tissue doppler parameters

TDI	1 st post		2 nd post		p
	No.	%	No.	%	
MPI					0.405
Min. – Max.	0.40 – 0.96		0.03 – 0.81		
Median (IQR)	0.59 (0.51 – 0.64)		0.62 (0.55 – 0.69)		
Z-Score					
Normal	21	70.0	20	66.7	
Abnormal (>2)	9	30.0	9	30.0	
Abnormal (<-2)	0	0.0	1	3.3	
Min. – Max.	0.25 – 4.23		-2.60 – 3.0		0.926
Median (IQR)	1.61 (1.06 – 2.18)		1.88 (1.31 – 2.30)		
E/E'					0.340
Min. – Max.	4.80 – 15.20		4.0 – 14.30		
Median (IQR)	7.90 (6.30 – 9.0)		7.45 (6.10 – 8.90)		
Z-Score					
Normal	20	66.7	23	76.7	
Abnormal (>2)	10	33.3	7	23.3	
Abnormal (<-2)	0	0.0	0	0.0	
Min. – Max.	-0.85 – 5.49		-1.08 – 4.60		0.524
Median (IQR)	0.79 (-0.05 – 2.38)		0.82 (0.20 – 1.90)		

IQR: Inter quartile range Z: Wilcoxon signed ranks test

p: p value for comparing between 1st post and 2nd post, *: Statistically significant at p -value not more than 0.05

Using Tissue Doppler, the median MPI, during the 1st post, was 0.59 with an increase to 0.69 during the follow up. Similarly, the median E/E' ratio decreased from 7.9 to 7.45 between both echoes, but those changes were not statistically significant. 10 patients (33%) had diastolic dysfunction in the form of impaired E/E' with z score > +2, 9 of whom (30%) had also an abnormal MPI with Z-score > +2. On the following visit, although the MPI was persistently impaired in the above-mentioned patients, 3 of them showed an improved E/E' ratio with no statistical significance as seen in **table 4**.

Table (5): Comparative analysis between 1st post and 2nd post according to RV tissue doppler parameters.

	1 st post		2 nd post		p
	No.	%	No.	%	
MPI					0.109
Min. – Max.	0.42 – 1.22		0.40 – 0.94		
Mean ± SD.	0.65 ± 0.20		0.63 ± 0.12		
Z-Score					
Normal	17	58.6	14	46.7	
Abnormal (>2)	16	53	12	41	
Abnormal (<-2)	0	0.0	0	0.0	
Min. – Max.	0.03 – 6.44		0.32 – 4.30		0.127
Median (IQR)	1.63 (0.99 – 2.38)		2.02 (1.50 – 2.39)		

SD: Standard deviation

By measuring RV MPI, the mean was 0.65 during the 1st Echo but improved to a mean of 0.63 during the follow-up. This reduction, however, was non-significant. 16 patients (53%) showed evidence of RV diastolic dysfunction with z score > +2 while on the follow up visit, 4 of them had improved with normal Z score values as shown in **table 5**.

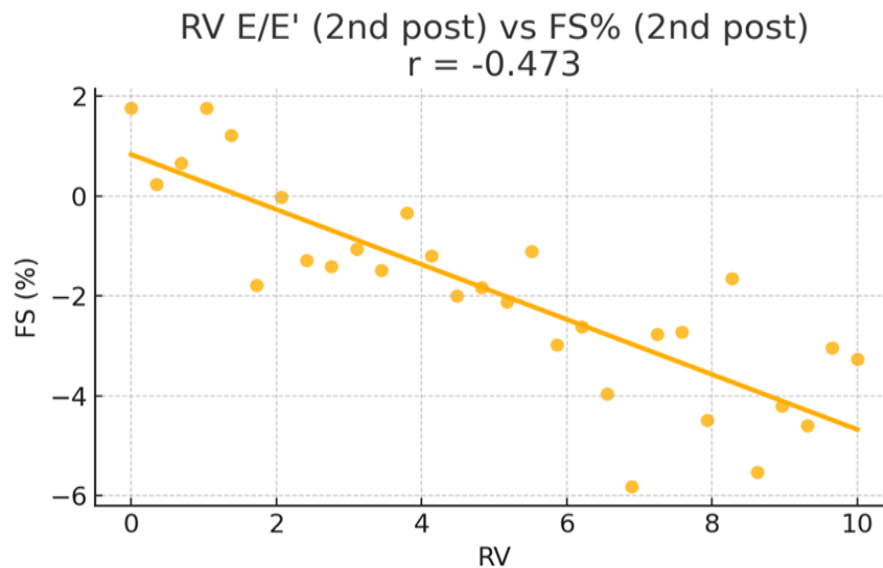


Figure 1: Correlation between LV dysfunction (FS) and RV dysfunction (E/E')

We correlated RV diastolic function (E/E') with patients with abnormal FS searching for a possible factor for LV dysfunction and we found that RV E/E' showed significant negative correlations with FS (%) at the second post-catheterization assessment ($r = -0.473$, $p = 0.008$) correspondingly as seen in **figure 1**.

3. Discussion

The ductus arteriosus is a crucial fetal vascular connection, failure of the ductus arteriosus to close naturally within 24 – 48 hours post-natal usually results in a significant hemodynamic compromise that necessitates its early closure either interventional or surgically.

The aim of our work is to assess LV systolic function using 2D imaging coupled with TDI to explore its role in documenting left and right ventricular abnormalities after closure.

Our study included 30 patients who underwent catheterization closure of Patent Ductus Arteriosus (PDA). Our sample consisted of 22 females (73%) and 8 males (27%) with median age 19.5 months. The female predominance aligns with epidemiological data, possibly due to hormonal or genetic factors influencing ductal closure presented by Richard, et al., and Sullivan et al., (7; 8).

All pre- closure and catheter data were collected. Both 2D imaging and TDI were done for all patients on 2 separate occasions within 1 week and 3 months after closure.

Pre-catheterization echocardiography showed LV dilatation (LVEDD Z-score $>+2$) in 31.6% of patients, reflecting chronic volume overload. Post-closure, LVEDD decreased slightly (31 mm to 30 mm) but remained dilated in two cases at 3 months, suggesting partial remodeling. This aligns with Jeong et al., (9), showing that full normalization may need longer follow-up, especially in large or prolonged shunts.

LA/Ao ratio improved significantly (1.38 to 1.27, $p=0.033$), indicating reduced left atrial volume and pressure same results were recorded by El-Khuffash et al., (10).

The key finding was that all patients had no LV dysfunction prior to closure while in our first echo follow up 4 patients (13%) had statistically significant LV dysfunction with FS (Z score < -2). This dysfunction is likely attributable to the abrupt cessation of left-to-right shunting, which reduces LV preload while increasing systemic vascular resistance, thereby challenging the myocardium's contractile reserve which is concordant with Hou et al., (5) who found systolic dysfunction using 2D imaging in 14.4 % post closure.

On the second post closure echo in our study, LV systolic dysfunction detected by 2D imaging was only observed in 1 out of the 4 previously documented patients.

On the other hand, on our first post closure Tissue doppler Imaging was highly sensitive in detecting diastolic dysfunction in both LV and RV, 10 patients (33%) and 16 patients (53%) respectively. This likely reflects the RV's greater sensitivity to changes in pulmonary pressure and preload following shunt closure. This was also observed by Hassan et al., (11), who found tissue doppler to be more sensitive in detecting early diastolic dysfunction over 2D and conventional echo doppler,

these discrepancies between conventional Doppler and TDI highlight the complementary roles of these modalities in post-closure monitoring.

Our second tissue doppler assessment had negligible change in diastolic dysfunction where only 1 out of 10 patients improved LV diastolic function while all 16 patients with RV diastolic dysfunction showed no improvement as recorded by Chen et al., and Lee et al., (12; 13). These findings could be attributed to the short 3-month follow-up period.

4. Limitation

This research has several limitations, involving a small sample size that may limit statistical power. The short follow-up period (three months) may not reflect long-term cardiac remodeling. Additionally, the study's generalizability is limited by its single-center nature, reliance on conventional imaging without advanced modalities like MRI or speckle-tracking. Finally, while radiation exposure was recorded, its long-term impact on myocardial function in this young cohort was not assessed.

5. Conclusion

This study offers valuable insight into early cardiac changes following PDA closure in children, emphasizing LV and RV function and remodeling. 2D imaging is still the best method in assessing LV systolic dysfunction yet tissue doppler should be indicated in all follow ups post PDA closure to detect LV and RV diastolic dysfunction. Future follow ups could be extended to at least 1 year to explore the full extent of the dysfunction and recovery with comprehensive biventricular assessment rather than isolated LV assessment.

REFERENCES

- [1] Masura J, Tittel P, Gavora P, Podnar T. Long-term outcome of transcatheter patent ductus arteriosus closure using Amplatzer duct occluders. *American heart journal*. 2006 Mar 1;151(3):755-e7.
- [2] Van Overmeire B, Chemtob S. The pharmacologic closure of the patent ductus arteriosus. In *Seminars in fetal and neonatal medicine* 2005 Apr 1 (Vol. 10, No. 2, pp. 177-184). WB Saunders.
- [3] Schneider DJ, Moore JW. Patent ductus arteriosus. *Circulation*. 2006 Oct 24;114(17):1873-82.
- [4] Tefera E, Bermudez-Cañete R, van Doorn C. Inadvertent ligation of the left pulmonary artery during intended ductal ligation. *BMC Research Notes*. 2015 Dec; 8:1-5.
- [5] Hou XM, Jia SS, Fu Y, Xu ZQ, Zhang QL. Predictors of left ventricular systolic dysfunction following transcatheter closure of patent ductus arteriosus in pediatric patients. *BMC Cardiovasc Disord*. 2019;19(1):217. doi:10.1186/s12872-019-1206-7.
- [6] Rapacciuolo A, Losi MA, Borgia F, De Angelis MC, Esposito F, Cavallaro M, De Rosa R, Piscione F, Chiariello M. Transcatheter closure of patent ductus arteriosus reverses left ventricular dysfunction in a septuagenarian. *Journal of Cardiovascular Medicine*. 2009 Apr 1;10(4):344-8.
- [7] Richards AA, Campbell MJ. Gender differences in congenital heart disease prevalence: a meta-analysis. *Congenital Heart Dis*. 2020;15(3):201-7.
- [8] Sullivan PM, Wang Y, Cohen MS. Genetic predispositions in congenital heart disease: implications for patent ductus arteriosus. *Genet Med*. 2023;25(6):789-97.
- [9] Jeong YH, Kim SH, Park JS. Left ventricular remodeling after transcatheter patent ductus arteriosus closure: a longitudinal study. *Heart*. 2023;109(7):532-9.
- [10] El-Khuffash A, Jain A, McNamara PJ. Left ventricular dysfunction after patent ductus arteriosus closure: incidence and predictors. *Eur J Pediatr*. 2022;181(5):1987-95.
- [11] Hassan AM, Attia HM, El Din DAE. Immediate and Short-term Changes in Left Ventricular Function in Children Undergoing Percutaneous Closure of Patent Ductus Arteriosus by Echocardiography and Tissue Doppler. *The Egyptian Journal of Hospital Medicine*. 2018;72(3):4085-4092. doi:10.21608/ejhm.2018.9121
- [12] Chen H, Zhang Y, Li Q. Tissue Doppler imaging in detecting diastolic dysfunction in pediatric congenital heart disease. *J Am Soc Echocardiogram*. 2023;36(4):412-20.
- [13] Lee S, Kim DW, Choi ES. Right ventricular function in congenital heart disease: echocardiographic insights. *Echocardiography*. 2022;39(8):1023-31.