Utility of Follow-Up Echocardiograms in Uncomplicated PDA Device Closures Performed During Infancy

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ABSTRACT

Introduction: Guidelines recommend lifelong follow-up with transthoracic echocardiograms (TTE) for patients who had a patent ductus arteriosus (PDA) device closure via catheterization. The goal of this study was to determine the utility of follow-up TTE in patients who underwent an uncomplicated PDA device closure during infancy.

Methods: Chart review was performed on patients who had a PDA closure at not more than 1 year of age between January 1, 2002 and June 1, 2020. Patients were excluded if they had other congenital heart disease, did not have a follow-up TTE at least 3 months after procedure, or had a velocity greater than 2.0 m/s in the left pulmonary artery (LPA) or descending aorta (DAo) on the first TTE at least 3 months after device placement. Time points included the first TTE after the procedure, first TTE at least 3 months after procedure, and the most recent TTE.

Results: Total of 147 infants met the inclusion criteria. Age and weight at initial procedure were 141 ± 217 days and 4.2 ± 2.8 kg. There was no significant difference in DAo velocity between initial and most recent TTE. LPA velocity and left ventricular diastolic Z score significantly decreased between initial and most recent TTE. Seventy-eight patients had repeat echocardiograms more than 1 year after PDA procedure with no change in clinical management. No patient underwent an intervention on the LPA or DAo for stenosis.

Conclusion: In patients who underwent an uncomplicated PDA closure during infancy, TTE parameters either stayed stable or improved over time. These findings need to be corroborated in larger studies with longer follow-up. If verified, the long-term TTE guidelines may need to be simplified for this patient population.

Keywords: PDA; Echocardiogram; Infants; Follow-up
Key Points

Guidelines recommend intermittent lifelong echocardiograms in patients who underwent transcatheter patent ductus arteriosus (PDA) device closure.

In this study, no significant complications with follow-up echocardiograms were noted in infant patients that had an uncomplicated PDA device closure.

Larger studies with longer follow-up are needed; but if corroborated, the need for routine lifelong echocardiograms in this population may need to be evaluated to determine the cost-effectiveness of this recommendation.

INTRODUCTION

A patent ductus arteriosus (PDA) represents the most common cardiovascular condition of preterm infants and its incidence is inversely related to gestational age at birth. Recent evidence suggests that 50–70% of infants born at less than 28 weeks of gestation have an open ductus at 2–5 months after birth [1]. Data among term infants suggest that PDAs are observed in approximately 1 in 2000 births, accounting for 5–10% of all congenital heart disease [2]. Usual treatment of a hemodynamically significant PDA has been via pharmacological or surgical methods depending on the clinical situation [3–5]. PDA device closure via catheterization has recently become the standard of care in infants and children that failed medical management and has increasingly gained wider acceptance in the premature population with US Food and Drug Administration (FDA)-approved devices for patients weighing as low as 700 g [6–8].

Complications associated with PDA device closure are well documented and include venous vascular damage, tricuspid valve damage, device embolization, left pulmonary artery stenosis, and descending aorta stenosis [9–19]. That said, most of these complications are noted relatively early after device placement [11, 12, 15, 19]. Close echocardiographic follow-up in patients with device complications are indicated. However, ACC/AHA/ASE/HRS/ISACHD/SCAI/SCCT/SCMR/SOPE guidelines also state that “in the first 2 years after PDA closure, either surgically or with a device, annual transthoracic echocardiogram (TTE) was rated appropriate (8/9). TTE every 5 years was rated appropriate for surveillance of patients after successful device closure, even with no or mild sequelae (7/9)” [20]. The utility of follow-up TTEs in infants undergoing an uncomplicated PDA device placement is unknown.

The goal of this study was to determine the utility of follow-up echocardiograms in patients who underwent an uncomplicated PDA device closure performed during infancy.

METHODS

This study was approved by the institutional review board at Nationwide Children’s Hospital. This study was performed in accordance with the Helsinki Declaration of 1964 and it later amendments. A single-center retrospective chart review on all patients that underwent a PDA device closure at most 1 year of age between January 1, 2002 and June 1, 2020 was performed. Infants were included if they had a PDA device placement in the catheterization laboratory and had no concerns on their follow-up TTE 3 months post device placement. A time period of at least 3 months was chosen because there did not appear to be clinically significant TTE differences in echocardiographic values between TTE performed between 3 and 12 months versus TTE performed more than 12 months post device placement. A time period of at least 3 months was chosen because there did not appear to be clinically significant TTE differences in echocardiographic values between TTE performed between 3 and 12 months versus TTE performed more than 12 months post device placement. A time period of at least 3 months was chosen because there did not appear to be clinically significant TTE differences in echocardiographic values between TTE performed between 3 and 12 months versus TTE performed more than 12 months post device placement. A time period of at least 3 months was chosen because there did not appear to be clinically significant TTE differences in echocardiographic values between TTE performed between 3 and 12 months versus TTE performed more than 12 months post device placement.
in the left pulmonary artery (LPA) or descending aorta (DAo) on the first TTE at least 3 months after device placement, or did not have a follow-up TTE at least 3 months after procedure. The patient population evaluated in this study therefore consisted of an uncomplicated cohort that essentially had no concerns either clinically (i.e., new murmur or discrepant upper/lower blood pressures) or via echocardiogram at the follow-up visit at least 3 months post PDA device placement. This is essentially the cohort of patients for which the guidelines recommend lifelong TTEs every 5 years.

Demographic data collected included gestational age, age, and weight at time of PDA device placement, and most recent clinical status. Type of PDA device was recorded. The first TTE post device placement, the first TTE at least 3 months post device placement, and the most recent TTE were reviewed. Echocardiographic data recorded included shortening fraction, ejection fraction, left ventricular internal diastolic dimension Z score, left pulmonary artery velocity, and descending aorta velocity.

Data are presented as means and standard deviations or medians and global ranges. Paired T tests were used for data analysis to compare echocardiographic data between time points. Significance was set at \( p < 0.05 \).

### RESULTS

A total of 245 patients were reviewed. Ninety-eight patients were excluded (congenital heart disease, \( n = 25 \); no follow-up echocardiogram at least 3 months post device placement, \( n = 53 \); velocity greater than 2.0 m/s in the LPA on the first TTE at least 3 months after device placement, \( n = 6 \); velocity greater than 2.0 m/s in the DAo on the first TTE at least 3 months after device placement, \( n = 9 \); and death 3 months or less after PDA device placement, \( n = 5 \)). Deaths were attributed to necrotizing enterocolitis, \( n = 2 \), pulmonary hypertension, \( n = 1 \), respiratory complications, \( n = 1 \), and neurological complications, \( n = 1 \). No death was due to complications from the PDA device. This study therefore consisted of 147 patients.

**Table 1** Procedural data

| Weight (kg) | \( n \) (total) |
|-------------|-----------------|
| \( \leq 1 \)   | 2               |
| \( 1 < x \leq 2 \) | 11              |
| \( 2 < x \leq 2.5 \) | 7               |
| \( > 2.5 \)  | 127             |

| Device                          | \( n \) |
|--------------------------------|--------|
| Amplatzer duct occluder         | 31     |
| Amplatzer duct occluder II      | 3      |
| Amplatzer duct occluder II AS/Piccolo | 33     |
| Amplatzer vascular plug         | 2      |
| Amplatzer vascular plug II      | 64     |
| Amplatzer vascular plug IV      | 1      |
| Nit occlud                      | 9      |
| Flipper detachable embolization coil | 4     |

Abbott Cardiovascular, Plymouth, MN, USA; B Braun Interventional Systems, Bethlehem, PA, USA; and Cook Medical, Bloomington, IN, USA

Gestational age was 29.3 ± 5.3 weeks (median 27.0 weeks, 21–41 weeks). Age and weight at PDA device procedure were 141 ± 217 days (median 94 days, 29–363 days) and 4.2 ± 2.8 kg (median 3.2 kg, 0.9–11.7 kg). Twenty patients weighed 2.5 kg or less. Devices used for PDA closure are presented in Table 1. Three patients died at least 3 months after PDA device placement (167 ± 47 days). Deaths were attributed to respiratory complications, \( n = 2 \) and sepsis/hypotension, \( n = 1 \). The last echocardiogram showed normal ventricular function and both LPA and DAo velocities were at most 2 m/s in these three patients. All other patients were noted to be clinically doing well at their last clinic visit with no cardiac medications being administered. Twenty-nine patients were discharged from the cardiology clinic. Thirty-seven patients were lost to follow-up, and 78 patients are still being followed in cardiology clinic.
Initial TTE was performed 7.4 ± 31.9 days, median 1 days (0–203 days) after PDA device placement, first follow-up TTE at least 3 months post device placement was performed at 12.7 ± 8.4 months, median 10.6 (3–48 months), and the most recent TTE was performed at 56.5 ± 41.8 months, median 41.7 (8–175 months) post device placement. There were no residual shunts noted in any of the patients on the first follow-up TTE at least 3 months post device placement. The left pulmonary artery velocity, ejection fraction, shortening fraction, and left ventricular internal diastolic diameter were significantly different between the initial TTE post device placement and the first follow-up TTE at least 3 months post device placement (Table 2). The left pulmonary artery velocity, shortening fraction, and left ventricular internal diastolic diameter were significantly different between the initial TTE post device placement and the most recent TTE (Table 3). Left pulmonary artery and descending aorta velocities over time are presented in Fig. 1.

No patient underwent a surgical or catheter intervention for left pulmonary artery or descending aorta stenosis. Seventy-eight patients had a total of 176 TTE at least 1 year after PDA device placement. No clinical changes were made on the basis of the follow-up TTE results based on clinical notes.

| Table 2 Echocardiographic changes: initial post echocardiogram to first follow-up echocardiogram |
|---------------------------------------------------------------|
| **Initial echocardiogram after PDA closure (n = 147)** | **First follow-up echocardiogram (n = 147)** | **p value** |
| DAo velocity (m/s) | 1.2 ± 0.3 | 1.2 ± 0.3 | 0.13 |
| LPA velocity (m/s) | 1.5 ± 0.5 | 1.2 ± 0.3 | < 0.01 |
| Ejection fraction (%) | 55.5 ± 12.0 | 64.3 ± 13.8 | < 0.01 |
| Shortening fraction (%) | 31.9 ± 7.5 | 37.8 ± 4.6 | < 0.01 |
| LVIDD Z score | 2.4 ± 0.5 | −0.7 ± 1.5 | < 0.01 |

*Significant difference

Table 3 Echocardiographic changes: initial post echocardiogram to most recent echocardiogram

| **Initial echocardiogram after PDA closure (n = 80)** | **Most recent echocardiogram (n = 80)** | **p value** |
|---------------------------------------------------------------|
| DAo velocity (m/s) | 1.2 ± 0.3 | 1.2 ± 0.3 | 0.73 |
| LPA velocity (m/s) | 1.4 ± 0.5* | 1.1 ± 0.3* | < 0.01 |
| Ejection fraction (%) | 55.8 ± 10.0 | 66.5 ± 5.8 | 0.06 |
| Shortening fraction (%) | 31.6 ± 7.5* | 37.8 ± 4.5* | < 0.01 |
| LVIDD Z score | 2.4 ± 0.5* | −0.6 ± 1.4* | < 0.01 |

*Significant difference

DAo descending aorta, LPA left pulmonary artery, LVIDD left ventricular internal diastolic dimension, PDA patent ductus arteriosus
DISCUSSION

Percutaneous PDA closure is progressively becoming more common [10, 15]. Immediate complications are well known, but longer-term results are less well delineated, especially in infants. Because of the lack of long-term data, current guidelines state that it is appropriate to obtain TTEs on a regular basis, even in patients with no or mild sequelae [20]. In this study, infants that underwent an uncomplicated PDA device closure had no long-term complications related to the PDA device. Follow-up surveillance TTEs for these infants did not change clinical management for these patients.

Reported complications after PDA device closure include venous/arterial vascular damage, tricuspid valve damage, device embolization, left pulmonary artery stenosis, and descending aorta stenosis [10, 13, 15, 19]. Most of these complications can be appreciated during the device procedure or relatively soon after the device procedure [10, 19]. Of these complications, left pulmonary artery and descending aorta stenosis are the complications that may be noted weeks to months after device placement [11, 12, 15, 22]. Previous studies in infants have noted increased velocities in the LPA and DAo immediately after PDA device placement that generally remained stable or improved over time [9, 11, 16]. Actual catheterization or surgical interventions to relieve LPA or DAo stenosis in infants is relatively rare with the incidence ranging from 0 to 4% [11–13, 16]. Most of these interventions also appeared to occur within the first few months after PDA device placement [11, 12, 15].

This study, using a cohort of infants undergoing percutaneous PDA closure without procedural complications, confirms the aforementioned published findings of improved ventricular function, normalization of left ventricular dimensions, and stable to decreasing velocities in the LPA and DAo with no need for catheter or surgical intervention in these vessels [11, 15, 22]. This study benefits from a longer follow-up compared to the previous studies in infants with a mean follow-up of 56.5 months and with the longest follow-up noted to be 14.5 years after device placement. Prior studies

![Velocity Changes Over Time](image)

**Fig. 1** Descending aorta and left pulmonary artery velocity changes over time post PDA device placement
mean follow-up periods ranged from approximately 1 to 3 years with most studies evaluating only the first few months after device placement [11, 15, 16, 19].

The earlier studies studying PDA device closure evaluated all infants that underwent closure whereas this study only evaluated a selected group of infants that had no concerns after PDA device placement after a 3-month time period. This may explain the lower incidence of complications reported in this study. This cohort was specifically chosen because of the recent guidelines that state that TTEs are generally appropriate for surveillance for the patient’s lifetime even in an asymptomatic patient with no or mild sequelae [20]. This study noted that there were no cardiac complications seen if there were no concerns on the first TTE at least 3 months post device placement. The long-term complications of worsening LPA or DAO stenosis did not occur in this infant cohort. The explanation may be that if there was no significant stenosis noted immediately post device placement, there would be no nidus for fibrosis and narrowing of the respective vessels, and somatic growth would prevent any subsequent stenosis [11, 16, 22]. These findings are consistent with a study among 315 patients in which most complications were found within 3 months post PDA device closure. That study concluded that “extended regular monitoring via echocardiography is not indicated after percutaneous PDA occlusion, and patients can be discharged safely from follow-up once there is no residual shunt or obstruction to the adjoining vessels” [21].

Though this study had the longest follow-up to date post PDA device placement with TTEs in an uncomplicated cohort of patients, it is always possible that even longer follow-up with routine TTEs would have uncovered late complications from the device placement. This single-center study cannot definitively say that late complications are never occurring. Only larger studies with longer follow-up can better define the utility of follow-up TTEs in asymptomatic patients with no concerns on follow-up TTE.

There were multiple limitations to this study. This was a single-center retrospective chart review study with all the inherent limitations of such a design. Furthermore, only a relatively small, selected population was evaluated. This study evaluated patients over an 18-year time span, so variances in individual and institutional management of PDA follow-up occurred and were not taken into account for analysis. There was no set echocardiographic timing schedule for these patients with the schedule determined by the primary cardiologist, so a more uniform analysis of TTE changes could not be performed. There were no long-term complications documented, so risk factors could not be determined. Approximately a quarter of patients were lost to follow-up so it is possible that late complications may have been missed. However, we think that this is unlikely
since these patients would have probably been referred back to our institution if clinical concerns had arisen.

CONCLUSION

Infants who had no echocardiographic concerns at the first follow-up TTE at least 3 months post PDA device placement had echocardiographic values that either stayed stable or improved over time. These findings need to be corroborated in larger studies with longer follow-up. If verified, the long-term TTE guidelines may need to be simplified for this patient population.

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Disclosures. Erin Van Pelt RDCS, Rachel Reo, Casey Lovelace, Anne Eshelman, Brian Beckman, Joanne Chisolm, Brian Boe, Carl Backes, and Clifford Cua all have nothing to disclose.

Compliance with Ethics Guidelines. This study was approved by the institutional review board at Nationwide Children’s Hospital (IRB STUDY 00001277). This study was performed in accordance with the Helsinki Declaration of 1964 and it later amendments.

Data Availability. Data underlying this article will be shared on reasonable request to the corresponding author.

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