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SPECIAL ISSUE ARTICLE

Comparative case studies: PDAs treated with medication, surgical ligation, and transcatheter device closure

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Abstract

The ductus arteriosus is a lifeline for the developing fetus prior to delivery, allowing the circulation of oxygen-rich blood from the placenta to bypass the lungs and perfuse the body. However, when the ductus fails to close after birth, the pressures can cause blood to shunt from the aorta back into the lungs, causing pulmonary edema. This is called a left-to-right shunt. The patent ductus arteriosus (PDA) can also shunt blood from the pulmonary arteries to the aorta, bypassing the lungs and causing oxygen-poor blood to mix with the oxygen-rich blood circulating to the body. This is called a right-to-left shunt. Too much shunting in either direction can cause significant long-term problems for the neonate. These three case studies compare the outcomes of patients with PDAs closed using different treatment techniques. The first patient's ductus arteriosus closed >2 months after birth following pharmacologic treatment. The second was closed by surgical ligation. The third was closed by transcatheter device closure.

KEYWORDS

case study, device closure, ductus arteriosus, ligation, patent, PDA, transcatheter

1 | INTRODUCTION

The ductus arteriosus is a lifeline for the developing fetus prior to delivery. In utero, fetal oxygenation occurs at the placenta rather than the lungs. As the oxygen-rich blood returns to the fetal body through the umbilical cord, it enters the heart through the inferior vena cava. Without the ductus arteriosus, that oxygen-rich blood would be pumped into the lungs, where most of the oxygen would be taken up prior to going to the brain and the rest of the body. The ductus arteriosus provides a shunt, whereby a majority of the blood flow bypasses the lungs, taking that oxygen-rich blood directly to the brain and other vital organs.¹ When the neonate is born, all of this changes. The pulmonary vasculature, which was a high-pressure environment in utero, now has pressures that are below that of the systemic vasculature.¹ When the ductus fails to close, the pressures can cause blood to shunt from the aorta back into the lungs, causing pulmonary edema. This is called a left-to-right shunt. The patent ductus arteriosus (PDA) can also shunt blood from the pulmonary arteries to the aorta, bypassing the lungs and causing oxygen-poor

blood to mix with the oxygen-rich blood circulating to the body. This is called a right-to-left shunt. Too much shunting in either direction can cause significant long-term problems for the neonate.

These three case studies compare the outcomes of patients with PDAs closed using different treatment techniques. The first patient's ductus arteriosus closed >2 months after birth following pharmacologic treatment. The second was closed by surgical ligation. The third was closed by transcatheter device closure.

2 | PATIENT 1

2.1 | Background

This patient was born at 27 weeks of gestation, male, and was delivered by a cesarean section secondary to maternal pregnancyinduced hypertension. Maternal serologies were negative for infection and compliance with prenatal care was good. There were no other prenatal complications. The patient was intubated in the delivery room due to poor respiratory effort and he continued to have



FIGURE 1 Widening pulse pressure through the first 10 weeks of this patient's life. Abbreviations: BP, blood pressure; mmHg, millimeters of mercury

severe respiratory distress following initial delivery room resuscitation. His medical care in the first weeks of life was dominated by high acuity respiratory needs. The patient required high frequency oscillating ventilation (HFOV) for the first 35 days of life (DOL), with the exception of a 28-hour period on high conventional ventilator settings, after which he returned to HFOV. This patient did not experience any of the gastrointestinal or neurological complications to which extremely premature infants are prone. His parents were at his bedside daily, interacting with both the patient and the medical care team appropriately.

2.2 | Diagnosis

Although the patient did not have an audible murmur on auscultation of heart sounds, he did exhibit mildly widening pulse pressures (Figure 1), labile oxygen saturations, and chest x-ray showed pulmonary edema possibly related to PDA. Due to these symptoms, an echocardiogram (echo) was done on DOL 10. The echo showed a small-sized PDA with left-to-right shunting.

2.3 | Plan and clinical course

Following initial diagnosis, the plan was to monitor the patient's PDA status clinically and repeat the echo as indicated. The patient was also started on furosemide therapy for pulmonary edema, but that was discontinued after 4 days due to lack of clinical response; his x-ray results and ventilator support requirements were unchanged.

On DOL 36, the echo was repeated. At this time, the patient was still on HFOV with high FiO_2 requirements (50%-80% FiO_2). This echo shows that the PDA is now large with all left-to-right shunting. At this time, the decision was made to treat the PDA for closure with acetaminophen. Another echo was done following the acetaminophen treatment but did not provide visibility of the ductus due to HFOV pressures. On DOL 46, the patient transitioned to a

conventional ventilator and an echo showed good visibility of the ductus—now small with some left-to-right shunting. Given the patient's improved pulmonary status and decrease in PDA size from large to small, his medical team felt that the PDA would continue to decrease in size and close fully without further intervention.

However, 8 days later, on DOL 54, a 3/6 systolic murmur was heard and an echo confirmed that the PDA was again large, now with bidirectional shunting. After a discussion between the cardiologist, the neonatologist, and the patient's parents, the decision was made to monitor the PDA without intervention at this time. The patient's clinical instability made the interdisciplinary team hesitant to pursue surgical intervention. The cardiology team recommended another course of acetaminophen, as that had reduced the size of the PDA previously. A complete metabolic panel was checked and the patient showed elevated liver enzymes indicating he was not a candidate for acetaminophen at this time.

The patient continued to tolerate conventional ventilator therapy with gradually decreasing FiO_2 . An echo on DOL 59 shows that the PDA has decreased in size to moderate, and finally on DOL 65 an echo showed no PDA. By now the patient was 2 months old and his corrected gestational age (CGA) was 36 weeks.

DOL 66-260, the ductus remained closed, but the patient continued to require significant respiratory support including tracheostomy, chronic diuretics, moderate-to-high ventilator support, and high FiO₂.

On DOL 261, when the patient was 8 months old, he developed a heart block. His cardiorespiratory status deteriorated quickly and he required increasing support to maintain cardiac and respiratory vital function.

The patient was removed from ventilator support to allow natural death surrounded by his family 11 days later.

2.4 | Discussion

The effects of a PDA on the developing cardiopulmonary system of a neonate are long-lasting. Patients with a hemodynamically

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significant PDA that remains open are at a much higher risk of morbidity and mortality.² As seen in this case, the continued overcirculation of the pulmonary vasculature results in increased afterload for the left ventricle and ultimately cardiac failure.

3 | PATIENT 2

3.1 | Background

This patient was a male newborn, delivered prematurely at 26 weeks of gestation via a cesarean section secondary to maternal HELLP syndrome and hypertensive crisis. His Apgar scores were 1 (1 minute), 3 (5 minutes), 4 (10 minutes), and 6 (15 minutes). He was intubated in the delivery room, given artificial surfactant as well as two doses of epinephrine via endotracheal tube. The patient was intubated for the first 5 DOL on moderate-low ventilator support. Extubation to noninvasive positive pressure ventilation (NIPPV) occurred on DOL 5, but due to increased bradycardia and desaturation events, he was re-intubated 12 hours later.

3.2 | Diagnosis

On DOL 6, the same day this patient required re-intubation, he also exhibited a loud murmur on auscultation, bounding pulses, and a widening pulse pressure that was >30 mm Hg. Due to suspicion of PDA contributing to the patient's status, an echo was ordered. The echo showed a large PDA.

3.3 | Plan and clinical course

Treatment with acetaminophen was ordered for this patient with the goal of closing the ductus. The patient received this treatment from DOL 6 to DOL 9. Five days after the completion of the acetaminophen therapy, a murmur was appreciated on exam and another echo was obtained to evaluate the ductus arteriosus. The second echo, completed on DOL 14, revealed a 2.2-mm PDA with left-toright shunting. A second course of acetaminophen was started for PDA closure. Another echo was done 2 days after the completion of this second round of medical treatment, which showed a moderate-sized PDA, 1.8 mm. After the two courses of the acetaminophen therapy were unsuccessful in closing the ductus arteriosus, the plan was made to complete a surgical ligation at the bedside because the infant was not stable enough for transport to the operating room.

On DOL 21, the day of the surgery, the cardiovascular surgery team came to the NICU for bedside surgical PDA ligation. The surgery began at 14:33. A left posterolateral thoracotomy was performed with a hemoclip placed around the ductus arteriosus. The surgery team did not report any complications; there was no blood loss or need for transfusion during surgery. The surgery team finished at 14:54. Immediately post-op, the patient was intubated on continuous mandatory ventilation (CMV): PIP 23, PEEP 9, rate 45 and FiO₂ at 25%. A chest x-ray, CBG, and hemoglobin/hematocrit were obtained post-op with a plan to repeat the x-ray at 20:00 to

monitor pulmonary edema. Morphine was ordered to be given every 4 hours as needed for pain.

Overnight, the patient remained stable. As he began to wake up and based on his blood gases, the ventilator mode was changed from CMV to SIMV. On post-op day (POD) 1, the patient remained intubated, but stable. Feedings were started and he received one dose of morphine for pain this day. On POD 2, an echo was done which did not show any residual ductal flow, indicating that the clip was successful in fully closing the PDA. The patient was extubated to NIPPV PIP 20, PEEP 6, rate 40, and FiO₂ of 21%.

Hydrochlorothiazide and spironolactone were started on POD 7 (DOL 28) for bronchopulmonary dysplasia. While this patient did have long-term respiratory issues, he did not experience postligation cardiac syndrome.

On DOL 44, 23 days after the surgery, he was weaned from NIPPV to high-flow binasal cannula. Pulmonary function continued to improve over the next 4 weeks and on DOL 72, his diuretics were discontinued. On DOL 86, he was successfully weaned to room air. Throughout this time, his growth and development continued well—he was transitioned from incubator to open crib and began bottle feeding.

This patient was discharged home on DOL 128 with no medications and no home oxygen or respiratory support required. While 128 days is a long time to stay in the NICU, because of this patient's early gestational age, he was at a CGA of 44 weeks at the time of discharge—only 4 weeks longer than his due date.

4 | PATIENT 3

4.1 | Background

This patient had a history of uncomplicated PDA; however, it was unable to be closed medically. This patient is a 27-week female di-di twin with a birth weight of 1.04 kg and 36.5 cm long born to a 26year-old G1 now P2 mother by vaginal delivery. Mother had an uncomplicated prenatal history and did receive antenatal steroids. The patient was intubated initially for surfactant and extubated to high flow nasal cannula on DOL 1. She was weaned to a bi-nasal cannula on DOL 11 and on room air by DOL 19. She was started on trophic feeds on DOL 2 and had a total fluid volume of 140 mL/kg/day. She has adequate urine output on DOL 1-3, above 1 mL/kg/hour.

4.2 | Diagnosis

On DOL 4, the patient had a 3/6 murmur, widened pulse pressures, and increasing metabolic acidosis. On DOL 8, the echo showed a large 3-mm PDA with all left-to-right shunting, mild left atrial dilation, and a normal ventricular size.

4.3 | Plan and clinical course

The team then initiated the first round of indomethacin treatment with 0.25 mg/kg \times 2 doses 24 hours apart. On DOL 11, the echo showed a moderate PDA 1.6-1.8 mm and a patent foramen ovale

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(PFO) with all left-to-right shunting. On DOL 12, the team initiated a second indomethacin course. On DOL 15, the echo showed moderate PDA at 2 mm, and the team started the first acetaminophen course of 15 mg/kg Q6 × 3 doses. DOL 19's echo revealed a small PDA 1.5 mm with all left-to-right shunting. On DOL 21, the team initiated a second course of acetaminophen with the same dose. On DOL 21-29, there was continued charting of a 3-5/6 murmur with bounding pulses. On DOL 31, there was a repeat echo with smallmoderate PDA of 1.8 mm with a PFO with left-to-right shunting and holodiastolic reversal in the aorta with suspected mild pulmonary valve stenosis.

On DOL 37, the team planned for a repeat echo in 6 days and on DOL 41 the echo revealed a moderate PDA with all left-to-right shunting, a small ASD with left-to-right shunting, and moderate pulmonary valve stenosis. It was then that a cardiologist was consulted where he/she stated this patient was at risk for pulmonary overcirculation and recommended a device closure of her PDA, and a pulmonary valvuloplasty for the pulmonary valve stenosis.

On DOL 42, the patient weighed 1.8 kg and had a CGA 33 4/7. The patient was transported by the Anesthesiology team to Cath Lab for PDA closure at 0707. The procedure began at 0835. The patient had access via the right femoral vein and had a balloon valvuloplasty of the pulmonary valve and transcatheter occlusion of PDA using a Microvascular Plug-5Q. There were no complications and minimal blood loss (approximately 3 mL). The procedure was finished and the patient was transported to the NICU at 1006. Immediately post-op, the patient was stable on vent with minimal settings (PIP of 18, PEEP of 5, and rate of 40 21% FiO₂). Post-op CBG revealed a 7.34 pH and CO₂ 46 with a base deficit of -1. Postoperatively, the patient had PRN morphine 0.05 mg/kg IV ordered, however never indicated nor given. The patient was extubated that same day at 1827 to high flow nasal cannula 2L 21%. One-hour postextubation CBG revealed the following, pH of 7.31, CO₂ of 49, and a base defecit of -2. The team began enteral feeds via nasogastric tube at 2115. The next day the patient was increased to full feeds, 120 mL/kg/day at 1300 on postop day 1, DOL 43. Until discharge, the patient never required FiO₂ or a ventilator support.

The patient took her first bottle on DOL 51 with a CGA 34.3. An echo on DOL 69 showed no residual PDA with mild pulmonary valve stenosis. On DOL 73 with a CGA of 36 5/7, the patient was discharged home weighing 2.48 kg. The patient had plans to follow-up with the Cardiology in 4 weeks and their primary care provider in 2-4 days after discharge. The choice of transcatheter closure was adequate to treat the patient's PDA and was less invasive than other options. This could be seen to increase her time to discharge; however, more research and comparison is needed on this topic. Note that some off-label and non-FDA approved device options were used in the care of this patient.

AUTHOR CONTRIBUTIONS

Ruth Seaton prepared and presented Patient 1's case study. Julia Peredo prepared and presented Patient 2's case study. Chandler Williams prepared and presented Patient 3's case study.

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