Fellows Column: Case Report: Intraoperative Identification of PDA During Surgical Ligation

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Background:

The ductus arteriosus is a vascular structure that connects the proximal descending aorta to the pulmonary artery. In fetal circulation, approximately 65% of cardiac output is from the right ventricle, and a patent ductus arteriosus (PDA) allows this right ventricular output to be diverted from its path into pulmonary circulation into the descending aorta. After birth, increased oxygen tension and systemic vascular resistance will cause a reversal from the fetal right-to-left flow to a neonatal left-to-right shunt (1, 2). It typically closes spontaneously after birth, but its persistence beyond a few weeks of life is abnormal.

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In extremely premature infants, closure of the ductus arteriosus can be significantly delayed, and a PDA is associated with increased morbidity and mortality (2,3). The hemodynamic impact of the PDA largely depends on the magnitude of shunting and the size of the cardiac vessels. Left-to-right shunting increases pulmonary flow and fluid volume, resulting in increased work of breathing and pulmonary edema. Increased flow to the left heart causes compensation by the left atrium and ventricle, leading to tachycardia, increased myocardial oxygen demand, and potential subendocardial ischemia (2). Closure of the PDA can be achieved pharmacologically with COX inhibitors, including Indomethacin and Ibuprofen, and surgically via catheter-based procedures or surgical ligation (4,5).

Patients with hemodynamically significant PDAs (hsPDA) demonstrate significant differences between pre and post-ductal perfusion indexes (PI). Echocardiography is the gold standard for diagnosing a PDA and a hemodynamically significant degree of shunt, particularly in extremely premature neonates (3). Saturation probes placed on the patient's right hand obtain a pre-ductal reading, and on either foot to obtain post-ductal readings. As such, studies have shown the effectiveness of using PI as a bedside measurement to identify PDA in premature infants and assess the post-operative success of PDA ligation (6). Following successful ligation of hsPDAs, significant increases in oxygen saturation occur (7).

Case presentation:

HPI:

A 615g male infant was born at 23 weeks and 6 days of gestational age by emergency cesarean section. Upon delivery, the infant was limp, apneic, and pulseless, with Apgar scores of 0, 3, 3, 5, and 7 at 1, 5, 10, 15, and 20 minutes, respectively. The infant was intubated, given PPO2 with 100% oxygen, and continued via an endotracheal tube. Epinephrine was administered via an endotracheal tube with continued cardiac compression. An umbilical vein catheter was then placed, and the patient was given epinephrine with NS bolus, after which the heart rate improved to greater than 100 bpm. Upon admission to the NICU, the patient was placed on a high-frequency jet ventilator, and UAC/UVC lines were placed.

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NICU Course:

The infant continued to experience hypoxemia, need for mechanical ventilation, and hemodynamic instability during his time in the NICU. An initial echocardiogram performed on day 5 of life showed a large PDA with a left-to-right flow and a small mid-septal interatrial communication with a left-to-right flow. Subsequent echos demonstrated increased left to right shunting, with repeat echos showing an increasing left atrium to aortic root diameter over 15 days. These ratios were measured at 1.2, 1.43, 1.5, and finally 1.6 3 days prior to surgical ligation. The standard of care within the Queen of the Valley Hospital NICU is to perform PDA ligation in symptomatic infants under 1000g whose PDAs do not spowere ntaneously close. Given the evidence that the PDA persisted, the decision to proceed with the surgical ligation was made. However, the surgery was delayed by eight days due to candidal tracheitis, for which cardiology and infectious disease recommended one week of treatment before surgery.

An echo performed four days prior to the PDA ligation, at which time the neonate was 20 days old, showed moderate PDA with a left to right flow (with peak gradient 10mmHg), LA/Aorta ratio of 1.6, moderate mid septal interatrial communication with a left to right flow, and mild tricuspid valve regurgitation (with peak TR jet at 42mmHg). Using these results, we proceeded with surgery.

Surgery

The patient was 970g and 24 days old at the time of surgery. A lateral thoracotomy with PDA ligation via titanium clips was performed (8). The patient was placed with right lateral decubitus and

left arm abducted, left chest prepped and draped. Pre-ductal and post-ductal monitors were placed on the patient's right hand and left foot. The incision was made on the posterolateral left chest below and parallel to the inferior scapula, entering the superior border of the third rib. After spreading through the musculature, the rib spreader was used to access the thoracic cavity. The left lung was retracted to expose the descending aorta, after which the pleura and fascia were dissected to reveal the PDA. The vagus nerve was also identified, and care was taken to avoid injury to the structure. There were no other visualized vessels in the field of vision, and a comparison was made to distinguish the aorta from the presumed PDA, noting that the walls of the aorta were thicker and whiter than the PDA. However, the PDA was large, approximately equal in visual diameter to the aorta, and longer, extending further into the cardiac region than expected.

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After visualizing the descending aorta, vagus nerve, and suspected PDA, vascular forceps, utilized as the test clamp, were placed on the PDA. Additionally, the pre and post-ductal monitoring was changed to the Masimo saturation monitor (Masimo rainbow SET), allowing for the display of aortic flow waveform, oxygen saturation level, and PI (perfusion index). Post-ductal oxygen saturation marginally increased (to approximately 94-96%), but after a few seconds, pre-ductal and post-ductal oxygen saturation (to mid-80%) and PI (perfusion index) decreased quickly. Of note, the decrease in pre-ductal and post-ductal PI was proportional, with a constant pre-ductal to post-ductal PI ratio of 2:1. There was also no significant increase in blood pressure. Due to the unexpected decrease in vital signs, test clamping was repeated several times, each with the same changes seen. Although the oxygen saturation and PI acutely increased and decreased when the PDA was clamped, the aortic wave flow stayed constant. This was one indication that flow through the aorta was not compromised while clamping the presumed PDA.

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Due to the abnormal changes in vital signs throughout the test clamping, the decision was made to perform an echocardiogram intraoperatively. Once the echo technician arrived, she followed sterile protocol and attempted to identify the PDA. However, she could not do so due to an artifact secondary to the mechanical ventilation. Therefore, focus was shifted to the vasculature, and the ascending and descending aorta were visualized. Doppler was used to confirm flow throughout the aorta, first without the test clamp placed and then with the test clamp. While clamping the presumed PDA, there was sufficient flow through the aorta at both time points. Therefore, with clear, strong flow visualized through the entirety of the aorta, despite the transitory decrease in O_2 saturation and PI, the team concurred that the clamped vessel was the PDA. The procedure proceeded with ligation via two titanium clips placed distally on the aortic end of the ductus to occlude its entire width. Hemostasis was ensured, and a left chest tube was placed. The chest was closed, the muscles were approximated, and the skin was closed. Ultimately, the procedure lasted approximately 3 hours, with the patient requiring fluid administration once.

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Post-operative Management:

The neonate experienced an adrenal crisis post-op day 1, requiring hydrocortisone and volume resuscitation. He also was placed on dopamine for two days to improve blood pressure and urine output, after which he was weaned off. He also experienced edema and hyperkalemia 1-day post-op, for which he received Lasix. Complications included "cath" toes of the first and second digits of the left foot on post-op day 1, which were improved after applying hot compresses to the inguinal region. Renal doppler was consequently performed and unremarkable. The chest tube was removed post-op day four without complications. Blood pressure continued improving through the post-operative period, and the patient was weaned off hydrocortisone.

Discussion:

This case highlights complications and atypical changes that may occur during surgical PDA ligation, with an innovative approach via intraoperative echocardiogram to confirm the identity of the PDA. The appearance of the PDA will vary greatly between neonates, and in this case, given the large size and length and unexpected changes in pre- and post-ductal oxygen monitoring, confirmation was required. Few case reports have reported such changes in vital signs (7, 8), although they are possible outcomes in a PDA ligation procedure. This case provides an example of the abnormalities that can occur during the procedure and a solution to resolve doubt regarding the identity of the ductus arteriosus.

The decision to perform the surgical ligation over alternative treat-

ment methods was clinical and institutional. The standard of care of the NICU at Queen of the Valley Hospital is to perform surgical PDA ligation, rather than medical treatment or other surgical methodologies, in infants under 1000g whose PDAs do not spontaneously close due to concerns for necrotizing enterocolitis (NEC) and intestinal underperfusion. The center has an extraordinarily low rate of spontaneous intestinal perforations and NEC with this standard of care. In this case, our patient was born at 615g with a persistent PDA visualized with serial echocardiograms in the 24 days of life. Indomethacin is typically used as a conservative treatment option for smaller PDAs. Device occlusion (catheter closure) is often not considered an alternative treatment due to the technical challenges of treating small infants under 1 kg and may have been difficult in our patient with aberrant anatomy (9).

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Classically, the expectation during PDA ligation is for post-ductal oxygen saturation and PI to acutely increase and remain high following placement of the test clamp and removal of the left-to-right shunt (7). This expectation was not met during the procedure, casting doubt about whether the vessel identified was the PDA or another vessel, such as the aorta. This abnormality can be explained by the physiological changes that occur with removing the left-to-right shunt provided by the PDA. Acutely, closure of the shunt can cause increased perfusion through the descending aorta, causing an acute, slight increase in PI and oxygen saturation; however, as the heart receives increased systemic volume, cardiac work, and systemic vascular resistance increase. This can cause PI to decrease, as there is no longer a low-resistance conduit for flow.

Moreover, this patient had a patent PDA for 24 days, so there was an element of heart failure, which would result in post-ligation changes of hypotension rather than hypertension. Of note, there are very few case reports detailing changes monitored during surgical ligation, as we have done in this report. Even further, there are none that detail problems encountered in the identification of the PDA.

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The use of echocardiograms during surgical ligation is a novel approach. Echocardiograms are used as the gold standard for the diagnosis of PDAs and the identification of hemodynamic significance. However, they are not used for intraoperative confirmation of PDA identity or flow strength through the vasculature as the test clamp is placed. During this procedure, we could not only identify flow through the ascending and descending aorta, but also measure the flow rate with the echocardiogram. According to the echo, numerical measurements were not recorded in real time but were verbally noted to improve after test clamping. Additionally, although we could not identify the PDA due to mechanical ventilator placement, monitoring changes made to the PDA itself before and after test clamping is also a possible use for the intraoperative echo.

Although not routinely seen, an acute post-ductal oxygenation increase followed by a decrease in both pre- and post-ductal oxygen levels is a possible outcome of ligation. To prevent future intraoperative uncertainty, increased reporting of intraoperative, pre-and post-operative changes in oxygenation monitoring and blood pressure can provide a more comprehensive timeline for surgical PDA ligations. Additionally, the innovative approach of using echocardiogram intraoperatively serves as a solution in cases where uncertainty in identifying the PDA does occur. Intraoperative echocardiography provides real-time information regarding the PDA and cardiac flow. This identifies the PDA and can also provide measurements for the strength of circulation, which may inform practitioners of the risk for future hemodynamic complications. PI changes that correlate with echocardiographic findings may be useful in avoiding the need for interoperative echocardiography.

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This report has multiple weaknesses. We describe only one case; no conclusion can be drawn from these findings. A full echocardiogram was not obtained during surgery, as the primary focus was confirming PDA identification. The use of echocardiography also increased the total duration of the surgery significantly, and the consequences of increased operating time must be weighed against its benefits in future use.

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