



PDA STENT

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| Surgical Specialty: | Interventional Cardiology |
| Authors: | Peggy Vogt, MD, Children's Healthcare of Atlanta and Emory University School of Medicine, Atlanta, GA Anna Hartzog, MD, Children's Healthcare of Atlanta and Emory University School of Medicine, Atlanta, GA |

Background:

- General Considerations
 - Patent ductus arteriosus (PDA) stent is a minimally invasive technique performed in the cardiac catheterization lab to establish a reliable source of pulmonary blood flow in cyanotic congenital heart disease.
 - In utero, the ductus arteriosus plays a critical role in diverting blood away from the underdeveloped fetal lungs by connecting the proximal descending aorta to the pulmonary artery. After birth, it typically closes functionally within a few days and anatomically within a few weeks. However, in some children with cyanotic congenital heart disease, the ductus arteriosus remains essential for maintaining adequate pulmonary blood flow.
 - These ductal-dependent lesions for pulmonary circulation include tricuspid atresia, pulmonary atresia with intact ventricular septum (PA-IVS), pulmonary atresia with ventricular septal defect (PA-VSD), critical pulmonary stenosis (PS), and tetralogy of Fallot with pulmonary stenosis (TOF-PS). To preserve ductal patency in these cases, a prostaglandin infusion is administered until a palliative intervention, such as a PDA stent, can be placed [1-3].
 - PDA stent can be performed as an alternative to a surgical systemic to pulmonary shunt, such as a modified Blalock-Taussig-Thomas shunt (mBTTs), or as part of a hybrid procedure in hypoplastic left heart syndrome (HLHS) that involves placement of bilateral pulmonary artery bands along with the PDA stent.
 - PDA stent is a relatively newer technique that became widespread in the 1990s as a less invasive procedure compared to mBTTs.
- Patient Considerations
 - PDA stenting is mostly performed in neonates and infants, and typically these patients are on a prostaglandin infusion pre-operatively to maintain ductal patency. Overall, the goal is to balance pulmonary vascular resistance (PVR) and systemic vascular resistance (SVR) to maintain adequate systemic perfusion and oxygenation as well as to avoid ductal closure (maintain prostaglandins, avoid hypoxia, acidosis, hypotension). Considerations given specific cardiac lesions include [4]:
 - TA: may have co-existing aortic arch hypoplasia or coarctation requiring balloon angioplasty during the same procedure.

- PA/IVS: may have RV-dependent coronary circulation, making it critical to maintain both RV preload and systemic blood pressure while carefully monitoring for myocardial ischemia.
- PAVSD: may have major aortopulmonary collaterals (MAPCAs) with multiple sources of pulmonary blood flow, creating over-circulation and congestive heart failure.
- Critical PS: Maintain SVR to reduce further right-to-left shunting.
- TOF-PS: increased risk of hypercyanotic spells ('tet' spells) and patients; may be on a phenylephrine or esmolol infusion pre-operatively.
- HLHS: may undergo a combined procedure as an alternative to stage 1 palliation with a surgeon and cardiology interventionalist, known as a hybrid procedure, involving a sternotomy to place bilateral PA bands.
- Associated Comorbidities/Syndromes
 - Since there is variation in the presentation of cardiac lesions requiring a PDA stent, there is also variation in possible associated comorbidities and syndromes.
 - DiGeorge syndrome: 22q11.2 deletion that presents with hypocalcemia, immune deficiency, and cleft palate; may be associated with PA/IVS, PAVSD, TOF-PS, etc.
 - Noonan syndrome: associated with critical PS. Patients may have distal branch pulmonary artery or aortic valve stenosis along with critical PS.
 - Trisomy 21: may be associated with several CHD lesions. Can also have bradycardia intraoperatively and difficult IV and airway access.

Anesthetic Planning:

- Pre-Anesthetic Evaluation
 - Additional labs/tests indicated during work-up:
 - Pre-operative echocardiogram to evaluate PDA anatomy, intracardiac structure, and cardiac function
 - CT or MRI may also be performed to delineate PDA anatomy
 - Baseline coagulation profile and complete blood count if clinical suspicion for coagulopathy
 - Genetic testing for DiGeorge syndrome, if indicated
 - Discussions to have with surgeon/family:
 - Cardiac catheterization laboratory procedures have a higher mortality rate of 0.28% compared to anesthesia-related mortality rate of 0.014% [5]. Given the high acuity patients and high-risk procedures performed in the cardiac catheterization lab, a detailed discussion of potential adverse events, including hemodynamic compromise, blood transfusion, and the possibility of ECMO should be discussed with the caregivers.
 - Code status and ECMO cannulation strategy should be detailed in the preoperative note.
 - Timing of prostaglandin infusion discontinuation is important as the duct should be small enough to accommodate a stent and prevent migration, but large enough to provide pulmonary blood flow and prevent hemodynamic compromise. The timing of discontinuation should be a shared decision between the proceduralist, intensivist, and anesthesiologist.
- Specific or Unique Room Set-Up Requirements
 - Airway:
 - It is imperative to have an endotracheal tube for a PDA stent. This procedure may necessitate manipulation of the PVR with ventilation strategies and may

- have temporary occlusion of pulmonary blood flow during the procedure, requiring control of oxygenation and ventilation.
- Drugs/Infusions:
 - If the PGE₁ infusion was discontinued prior to transport to the catheterization lab, it should be in line or immediately available to restart in case of hemodynamic instability.
 - Vasoactive infusions such as epinephrine, phenylephrine, calcium gluconate, or vasopressin depending on the patient's cardiac lesion, may be required prior to stent placement to maintain hemodynamics.
 - Monitors:
 - Standard ASA monitors include a three or five-lead electrocardiogram, noninvasive blood pressure, arterial oxygen saturation, temperature, and end-tidal CO₂.
 - A peripheral invasive arterial line is used for hemodynamic monitoring during and after the procedure. While an arterial sheath may be utilized by the interventionalist for intra-procedural monitoring, some institutions endorse placement of a peripheral arterial line for continued post-procedural monitoring in the ICU, while others do not.
 - Somatic near-infrared spectroscopy (NIRS) is utilized to monitor organ perfusion.
 - Blood Availability (if indicated):
 - Cross-matched blood should be present in the room or readily available in the event of significant intra-procedure bleeding or need for ECMO.
 - ICU Bed Availability (if indicated):
 - The patient will require intensive care monitoring after placement of a PDA stent. Depending on the institution, this may be in the pediatric ICU (PICU), cardiac ICU (CICU), or neonatal ICU (NICU).
 - Other Indicated Resources (ex. ECMO standby):
 - In the event of ductal closure causing hemodynamic instability, ECMO should be readily available at the center. There should be a discussion between the proceduralist, intensivist, surgeon, and anesthesiologist about the plan for ECMO in high-risk patients (i.e., circuit primed in the room with the surgeon vs available in the building). Based on recent literature, there are "acceptable" and "ideal" levels of ECMO support for PDA stent placement. An 'acceptable' level is the surgeon off campus or scrubbed into a different procedure and available to make incision within 1 hour. An "ideal" level of ECMO support would be surgeon on site and able to make incision in less than 15 minutes [6].
 - Depending on the institutional guidelines for ECMO activation and patient stability pre-procedure, this may involve an ECMO setup in the room or immediate availability.

Intraoperative Considerations:

- General
 - Anesthetic goals are to maintain preload and contractility as well as to avoid decreases in SVR and increases in PVR (avoid hypoxia, hypercarbia, acidosis, sympathetic stimulation).
 - Hypothermia is common in the catheterization lab due to skin exposure for vascular access and frequent flushing of the catheters and sheaths. Forced air warming blanket and warmed fluids should be utilized.

- Avoiding hypoglycemia, especially in the neonatal population, is crucial.
- Induction
 - These procedures are usually performed in neonates, and premedication in this population is usually not necessary. However, if the patient is presenting with a delayed diagnosis, IV or IM ketamine or midazolam is an appropriate premedication for separation anxiety.
 - One should have IV access preoperatively since the patient should be on a PGE₁ infusion; therefore, IV induction is preferred. Based on the patient's age, acuity, and biventricular function, IV induction with ketamine or etomidate, combined with opioids and paralytic, is appropriate.
 - If IV access has been dislodged or no longer patent upon arrival to the catheterization lab, inhalational induction with slow titration in normal biventricular function patients is generally well tolerated. IV access should be quickly obtained after induction. However, IV induction is safer given the combination of lowering PVR with oxygen during an inhalational induction, decreasing SVR with high-dose volatiles, inability to give IV vasoactives or emergency drugs without IV access, and overall difficult IV placement in neonates or infants who have been in the ICU.
- Positioning
 - The lateral and anteroposterior cameras in the catheterization lab restrict the anesthesiologist's access to both the patient and the workspace. Ensuring appropriate patient padding before the start of the procedure is essential to minimize the risk of pressure injuries.
 - Depending on the vascular approach of the interventionalist, patient positioning may change.
 - Carotid access technique involves turning the patient 180 degrees from the anesthesiologist (i.e., feet at the head of the table) to allow the interventionalist a conventional technical approach. This increases the distance to the airway for the anesthesiology team.
 - Patient arms may be positioned above their heads for adequate intraprocedural imaging. Appropriate padding to avoid nerve traction and brachial plexus injury is particularly important in this position.
- Maintenance
 - Maintenance of anesthesia will depend on the patient's specific cardiac lesion, clinical status, and age. Typically, in the neonatal population presenting for a PDA stent, a combination of low-dose volatile, opioids, and paralytic are well tolerated to maintain hemodynamics. The patient will most likely return to the ICU intubated; therefore, long-acting opioids or other sedative options are appropriate.
- Hemodynamic/Physiologic goals
 - Hemodynamic goals:
 - Pre-stent deployment goals are to maintain preload and contractility while avoiding increases in PVR (hypoxia, acidosis, hypercarbia) and decreases in SVR.
 - Once the stent is deployed, excessive pulmonary blood flow can cause pulmonary congestion and decreased aortic diastolic pressure, resulting in myocardial ischemia. Therefore, caution with excessive FiO₂ is imperative and communication with the cardiology proceduralist regarding FiO₂ is equally imperative.
 - Arterial oxygen saturation goals:
 - An SpO₂ of 75-85% is the goal pre-stent placement; though, this is patient dependent (i.e., may need 100% FiO₂ to optimize oxygenation for the limited

pulmonary blood flow in the event of duct constriction from discontinuation of PGE₁). Post-stent placement, the hemodynamic goals are similar to balance pulmonary and systemic blood flow (i.e., SpO₂ usually 75-85%).

- Surgical Considerations
 - The vascular approach will vary depending on the origin and morphology of the PDA. For straight PDAs (common in PA/IVS, critical PS, tricuspid atresia), femoral or carotid artery access is typical. Tortuous PDAs may require a femoral vein approach (commonly associated with TOF, single ventricle, complex cyanotic congenital heart disease).
 - Intra-procedure transthoracic echo by the anesthesiologist or cardiologist is imperative to confirm the correct placement of the stent across the PDA without obstruction of the aorta or pulmonary arteries.
 - Appropriate size defibrillator pads should be immediately available in the event of dysrhythmias that can occur as the catheters course through the heart. First-line treatment would be to withdraw the catheter.
- Emergence/Disposition
 - Anticipate returning to the ICU intubated. An opioid or dexmedetomidine infusion for sedation may be necessary for transport and transfer of care to the ICU team.
- Post-op Care
 - ICU-level care post-procedurally.

Case-Specific Complications/Pitfalls

- Acute complications include ductal spasm, stent migration, and acute stent thrombosis [1, 5].
 - Ductal spasm: With tortuous PDAs, the unfolding of the ductus can be unpredictable after wire removal and result in ductal spasm of the unstented portion. This presents as cyanosis and hemodynamic instability. For this reason, a ductal stent length longer than the measured length from the PA to the aorta may be placed, which may result in what's known as jailing of the PA (or PA jailing).
 - PDA stent length is based on echocardiogram and intra-procedural catheterization measurements, whereas PDA stent diameter is based on patient weight.
 - PA jailing does not increase mortality, ICU stay, or ventilation duration if the PAs are recruited immediately by catheter dilation. However, a PDA stent that 'jails' the PAs does require pulmonary artery plasty (PA plasty) at the next surgical palliation.
 - PDA stent migration: In the event of stent migration, the interventionalist can attempt to retrieve or reposition the stent (i.e., push it into a peripheral pulmonary branch to be retrieved during the next surgical repair). In the worst-case scenario, a patient may require emergent surgery to retrieve the stent and place a surgical shunt.
 - Acute stent thrombosis: In the event of acute stent thrombosis, the interventionalist can attempt to break the thrombus by inflating a balloon across the ductus. The use of thrombolytic therapy should be weighed against the risk of coagulopathy and bleeding if an emergent surgical shunt needs to be placed.

- Long-term outcomes: re-intervention rate, PA growth, length of hospital stay, overall mortality
 - PDA stents are associated with lower mortality and shorter hospital stays compared to surgical systemic-to-pulmonary shunts. However, stenting of the PDA carries a higher rate of re-intervention, likely due to the need for frequent catheterizations and unplanned procedures. An advantage of the PDA stent is its adjustability because it can be enlarged through balloon angioplasty in the cardiac catheterization lab as the patient grows or clinical needs change [1].

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Reviewed by:

Reviewer #1: Andrew J. Giustini, MD, PhD, Oregon Health & Science University

Reviewer #2: Clayre Tanis-Arens, DO, Indiana University School of Medicine

Reviewer #3: Bridget K. Pearce, M.D., University of Michigan
