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Patent Ductus Arteriosus

1.1 Morphology

In fetus the high-resistance pulmonary circulation diverts majority of right ventricular output through the ductus arteriosus into the descending aorta. Though the structure of ductus appears similar to adjacent main pulmonary artery and descending aorta, the media of the ductus is composed of layers of smooth muscle fibers within loose and concentric layers of elastic tissue. The intima is thickened and irregular, with abundant mucoid material, often termed as intimal cushions.

The patency of the ductus arteriosus in fetus is maintained by a low fetal oxygen tension, prostaglandin [PGE_2], and prostacyclin [PGI_2]. Locally produced and circulating PGE_2 and PGI_2 in the fetus cause vasodilatation of the ductus arteriosus, through interaction with ductal prostanoid receptors.

After birth, the abrupt increase inoxygen tension inhibits ductal smooth muscle potassium channels, which results in an influx of calcium and ductal constriction. The circulating PGE_2 and PGI_2 levels decrease due to metabolism in functioning lungs and elimination of the placental source. The medial smooth muscle fibers contract resulting in lumen obliteration and shortening of the ductus arteriosus. Functional complete closure usually occurs within 24 to 48 hours of birth in term neonates. Within the next 2 to 3 weeks, subintimal disruption and proliferation result in fibrosis, obliteration of the lumen and persists as the ligamentum arteriosum.

The patent ductus arteriosus (PDA) connects the left pulmonary artery near its origin to the descending aorta just distal to the left subclavian artery. It occurs in a wide variety of configurations and sizes:

- *Type A* (“conical”) ductus has a well-defined aortic ampulla and constriction near the pulmonary artery end (most common).
- *Type B* (“window”) is a very large ductus, with a very short length.

- *Type C* (“tubular”) ductus, which is without constrictions.
- *Type D* (“complex”) ductus, which has multiple constrictions.
- *Type E* (“elongated”) ductus, with the constriction remote from the anterior edge of the trachea.

1.2 Pathophysiology

Blood flow in the ductus is dynamic and pulsatile, and the elasticity of the ductus wall affects the impedance to blood flow**.** The magnitude of shunting, through the ductus depends on the following as mentioned below:

1) The flow resistance that is dependent on shape, size, and configuration of the ductus arteriosus.
2) The pressure gradient between the aorta and the pulmonary artery, which is dynamic with systolic and diastolic components. The pressure gradient depends largely on pulmonary and systemic vascular resistances and cardiac output. The impact of changes in pulmonary and systemic resistances is greater in large ductus that has less flow resistance.

Left-to-right shunting through the ductus arteriosus results in pulmonary over-circulation and left heart volume overload, increased left atrial and left ventricular end-diastolic pressures with increased interstitial fluid in the lungs, which causes decreased lung compliance with increased work of breathing. The left ventricle compensates by increasing stroke volume and develops eventually hypertrophy to normalize the wall stress. Increased sympathetic activity and circulating catecholamines result in increased contractility and heart rate. The aortic diastolic blood pressure decreases due to diastolic “runoff” through the patent ductus. This, coupled with shorter diastolic time due to tachycardia, increased myocardial wall tension from LV dilatation, and increased myocardial oxygen demand result in subendocardial ischemia.

1.3 Sequelae of PDA

1.3.1 Congestive Heart Failure

Children and adults with large patent ductus frequently develop symptoms of CHF due to pulmonary overcirculation though patients with small to moderate ductus often remain asymptomatic during infancy and childhood. In the adult, heart failure is frequently associated with atrial flutter or fibrillation.

1.3.2 Pulmonary Vascular Disease

With long-standing left-to-right shunting, exposure of the pulmonary artery to high-pressure and high flow, leads to progressive increase in pulmonary vascular resistance that exceeds the systemic vascular resistance and the ductal shunting reverses (right to left or Eisenmengers).

In rare infants and children with a large patent ductus and pulmonary hypertension, the normal postnatal fall in pulmonary vascular resistance is not seen even after closure of the ductus. In such patients the pulmonary vascular disease may progress.

1.3.3 Bacterial Endocarditis

Infective endarteritis associated with ductus arteriosus remains a significant risk, and vegetations usually occur on the pulmonary artery end of the ductus, and embolic events are usually of the lung rather than the systemic circulation.

1.3.4 Aneurysm of the Ductus Arteriosus

Aneurysm of the ductus arteriosus (incidence of 8%) that is detected by neonatal echocardiography resolves spontaneously with ductal closure and thrombosis, without clinically apparent complications. Ductal aneurysm that commonly presents in infancy may develop after infective endarteritis, surgical

closure, or transcatheter coil occlusion, and it is associated in 25% of patients with an underlying disorder such as trisomy 21, type IV Ehlers-Danlos syndrome, or Marfan's syndrome.

Rarely, an aneurysm may present with symptoms of a thoracic mass, including hoarseness due to left vocal cord paralysis and left bronchial obstruction. Surgical resection is indicated if there is a functional compromise of adjacent structures, persistent patency of the ductus, thrombus that extends into adjacent vessels with evidence of thromboembolic events, or underlying connective tissue disease.

1.3.5 Recurrent Laryngeal Nerve Paralysis

Pulmonary hypertension may lead to nerve paralysis, even without aneurysm, due to impingement of the nerve as it courses through the triangle formed by enlarged pulmonary artery, the aortic arch, and the ductus.

1.3.6 Spontaneous Rupture

Pulmonary hypertension may lead to dissection and/or spontaneous rupture of an aneurysmal dilated pulmonary artery or acute aortic dissection.

1.4 Indications for Closure of PDA

1) Any symptomatic child or adult from significant left-to-right shunting.
2) Asymptomatic patients but with a significant left-to-right shunting that results in the left heart enlargement. Surgery minimizes the risk of future complications.
3) Patients with modest elevation in pulmonary vascular resistance as outcomes after PDA closure have been very good.
4) Routine closure of any PDA in children and young adults is performed even in a silent or incidentally discovered ones or the duct with a small shunt due

to risk of endocarditis. Exception to this rule may be applied in older adults. In children, the surgery is performed preferably before school going age.

5) Selected patients with Eisenmenger's syndrome: Elimination of the shunt reduces pulmonary blood flow and pulmonary artery pressure even if the pulmonary vascular resistance remains elevated.

   If PVR > 8 U/m^2, lung biopsy has been recommended to determine eligibility for closure, but the lung biopsy may not be reliable to predict the risk and operability. The changes consistent with severe and irreversible pulmonary vascular disease may also completely resolve after closure of the PDA in some. Reactivity of the pulmonary vascular bed to pulmonary vasodilating agents, significant reduction of pulmonary artery pressure, and resistance during the test occlusion may offer reassurance with regard to reversibility, but absence of such evidence does not exclude the possibility of reversibility in the long term.

6) Prematurity and PDA: Management is somewhat controversial. There is an increased incidence of PDA in premature infants, and it correlates with postnatal age and low birth weight. Presence of this lesion produces significant left to right shunting with increased PBF and development of congestive failure which further worsens existing hyaline membrane disease, and increases the need for prolonged mechanical ventilation which in turn increases the incidence of bronchopulmonary dysplasia, retrolental fibroplasias, and potentiate the complications such as intraventricular hemorrhage, necrotizing enterocolitis, and intolerance to enteral feeds.

If significant shunt from PDA is confirmed on a physical examination (bounding pulses, hyperactive precordium with a continuous murmur), chest roentgenogram, and echocardiogram, *the initial treatment is conservative* with fluid restriction, diuretics, and correction of anemia with PRBC (packed red blood

cell) infusion. The duct closes as the infant matures. *Failure of conservative therapy is an indication for pharmacological or surgical intervention.*

Indomethacin (pharmacological intervention) is as effective as surgical ligation for duct closure and prevention of complications. The increased incidence of bleeding complications other than intraventricular hemorrhage is noted with indomethacin use. The incidence of retinopathy of prematurity is higher with the primary surgical closure.

Failure of indomethacin therapy or onset of the drug related complications (diastolic ventricular dysfunction, aggravation of pulmonary edema, renal dysfunction, platelet dysfunction, and gastrointestinal hemorrhage) is an indication for surgical ligation. The success of indomethacin is related to birth weight and postnatal age with increased incidence of failure rate in low birth weight infants, therefore, primary surgical ligation may be indicated in these infants.

There is current trend towards earlier intervention for duct closure in premature infants before development of a shunt. The indomethacin is given prophylactically in < 1000 g premature infant with signs of PDA as significant left to right shunt develops in most of these infants.

In infants with birth weight of > 1000 g, there is no benefit of initiation of therapy before development of significant shunt. The failure of conservative therapy after development of significant shunt and pharmacological Rx with first or second course of indomethacin is an indication for surgical ligation.

Though percutaneous catheter occlusion of PDA in preterm infants born at a weight of < 4kg (median weight of 2.9 kg) is safe and may improve respiratory status, significant adverse events including an arterial injury is reported in 1/3 of cases. More randomized clinical trials are, therefore, needed to compare the outcomes of surgical ligation vs catheter occlusion in low birth weight infants.

1.5 Surgical Techniques

Surgery is performed through a left anterior or posterior thoracotomy (see Figure 1.1).

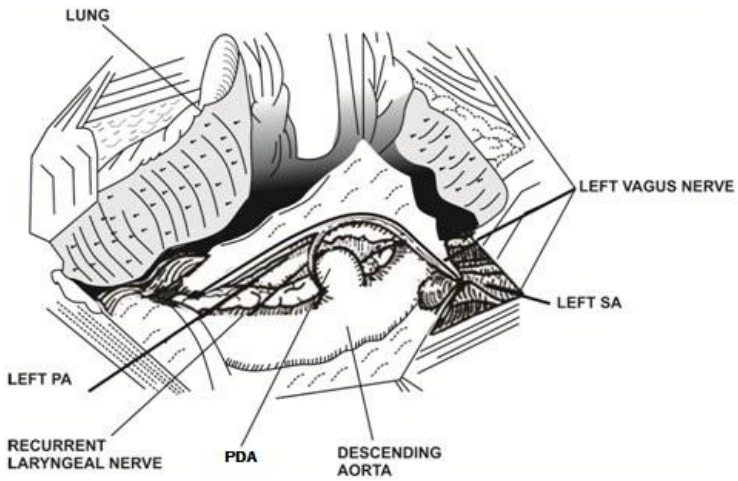

Figure 1.1 *Diagram showing patent ductus arteriosus exposed through left thoracotomy incision. Note an incision in the mediastinal pleura and dissection of areolar tissue overlying the arch of aorta and descending aorta exposed underlying vascular structures, including patent ductus arteriosus and left recurrent laryngeal nerve. PDA= patent ductus arteriosus, PA= pulmonary artery, SA= subclavian artery.*

1.5.1 Ligation

Ligation: It is the choice in young infants and children.

1.5.2 Division or Multiple Suture Ligation / Transfixion

Division or multiple suture ligation / transfixion: It is appropriate in older children.

1.5.3 Division

Division: It is a choice for the large ductus (> 10 mm) in adults and in those associated with moderate pulmonary hypertension.

1.5.4 Calcified Ductus and Aneurysm of Ductus

Calcified ductus and Aneurysm of the ductus: In older adults with circumferential calcification of the duct or with aneurysm of the ductus, the surgery is performed with either use of CPB (cardiopulmonary bypass) and cardioplegic arrest, or without CPB using a heparin bonded shunt or without a shunt. The aorta is clamped below and above the ductus. Division of the duct is done; PA end of the duct is controlled by a balloon occlusion. The closure of pulmonary arteriotomy and patch closure of aorta is performed. The aneurysm of the duct is totally excised.

1.6 Postoperative Management

The postoperative course following the closure of isolated patent ductus arteriosus is usually benign. The hospital stay averages 2 to 3 days, but it is longer for premature infants or infants who are in significant congestive heart failure preoperatively.

1.6.1 Invasive Monitors

Arterial line and central venous catheter (If infant is in congestive heart failure preoperatively).

PA line may be optional in patients with moderate pulmonary hypertension and elevated PVR (pulmonary vascular resistance).

1.6.2 Vasoactive Drug Infusions

Rarely are required for postoperative management.

1.6.3 Systemic Hypertension

Not encountered usually, but the diastolic pressure may rise 10 to 20 mm Hg from the baseline after ligation, due to elevated systemic vascular resistance.

1.6.4 Postoperative Bleeding

It is very rare. Injury may result during repair of a calcified ductus which may be seen in the adults. Intraoperative hemorrhage may occur during dissection of a friable duct.

1.6.5 Hoarseness

It is occasionally encountered as the recurrent laryngeal branch of vagus nerve is in proximity to the operative site. It is usually transient and resolves spontaneously.

1.6.6 Diaphragmatic Paralysis

Diaphragmatic paralysis: May occur due to phrenic nerve injury.

1.6.7 Chylothorax

Chylothorax: It is very rare due to injury to thoracic duct, especially if the dissection is performed in deeper plane than required (see Section I Chapter 12).

1.6.8 Ligation of Left Pulmonary Artery or Hypoplastic Arch

Ligation of Left pulmonary artery or hypoplastic arch: May inadvertently occur.

1.6.9 Cor-pulmonale

In some infants with pulmonary hypertension and ductus, the pulmonary vascular resistance fails to regress after closure and progressive increase in pulmonary vascular resistance would lead to high pulmonary artery pressure (60 to 70 mm Hg), right ventricular failure, and right to left shunting with severe hypoxia.