CHIRURGIE CARDIAQUE / CARDIAC SURGERY

CURRENT PROCEDURES FOR PATENT DUCTUS ARTERIOSUS (PDA) INTERRUPTION / TECHNIQUES CHIRURGICALES USUELLES D'INTERRUPTION DE LA PERSISTANCE DU CANAL ARTERIEL (PCA)

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Summary

The present review has focused on current surgical approaches to occlude the PDA. At present, the majority of PDA's are recognized and treated during the neonatal period. However, there still remains a significant prevalence of PDA's in children and adults, especially in developing countries and emerging economies. The relative and absolute indications for treatment continue to evolve. Surgery remains a proven and effective methodolgy, however the currently available material for percutaneous interventional procedures, with a more user friendly nature and long term proven risk free status, have gradually changed the balance towards a less invasive non surgical approach. Yet the gold standard for results and comparison remains the open surgical techniques in the children/adult group as noted in the Mavroudis et al.[77] experience from Children's Memorial hospital in Chicago. Over a 46 year period from 1947 to 1993, 1106 patients had open division or ligation of a PDA with 0% mortality, 4% morbidity, 0% recurrence, and contemporary length of stay <3 days.

Key Words : Ductus Arteriosus, Patent Ductus Arteriosus, Ligation, Ductus, PDA, Division

Introduction / Background

The PDA was described by Galen in 131 AD, Carono in 1593, and again by Botallo in the 15th century (eponym- ductus Botalli). Rokitanski highlited PDA as a specific entity in his handbook in 1844, and again in his monograph in 1852[1]. PDA is a common congenital heart lesion with an incidence of 1/1600-2000 in term infants, and an incidence of 20-30% in premature infants. PDAs account for 5-10% of all congenital heart diseases. If one considers the silent PDAs as well, the incidence has been estimated at 1 in 500[2,3]. The female-to-male ratio is 2:1. The incidence of PDAs is higher in rubella infections during the first trimester of pregnancy, in low birth weight (LBW) infants, at higher altitudes, and coexistent congenital heart defects. In full term infants, genetic coding of prostaglandin receptors and smooth muscle cell regulators may also play a role in an increased incidence. The Society of Thoracic Surgery Congenital Surgery database from 2006-2010 reported a 7.4% incidence of PDAs, and an incidence of 7.8% PDA operations from a total of 88,989 cases[4].

As first noted by William Harvey in 1628, a PDA is an essential component of fetal circulation[2,6]. The embryological development of the ductus arises from the persistent distal left sixth aortic arch at 6th gestational week (figure 1, 2)[7]. It ranges from 10-15mm in length, and is 4 to 8mm in diameter. The ductus extends from the pulmonary confluence as a continuation of the main pulmonary artery, and terminates in the left descending aorta just distal to the left subclavian artery. The ductus is located on the left side. However, if a right aortic arch is present, with either a right or left descending thoracic aorta, it

could be located on either the right or left side[8]. Figure 3 depicts the angiographic spectrum of PDA's used to guide interventional closure of the PDA[2].

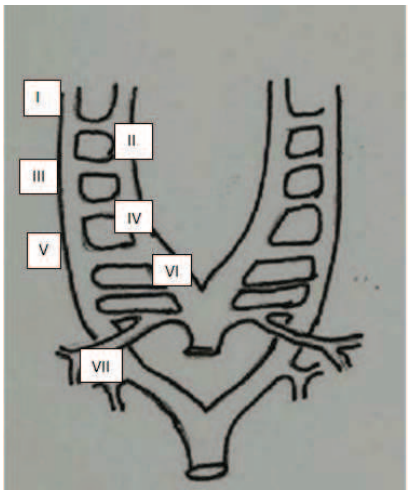

Figure 1: Embryonic development of PDA from left 6th aortic arch (7)

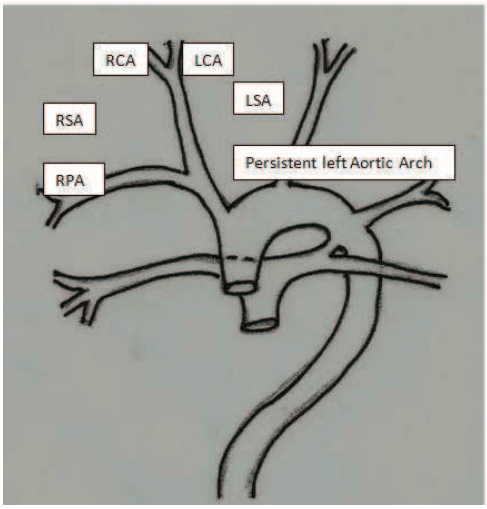

Figure 2: Normal aortic arch system with persistent left aortic arch (7)

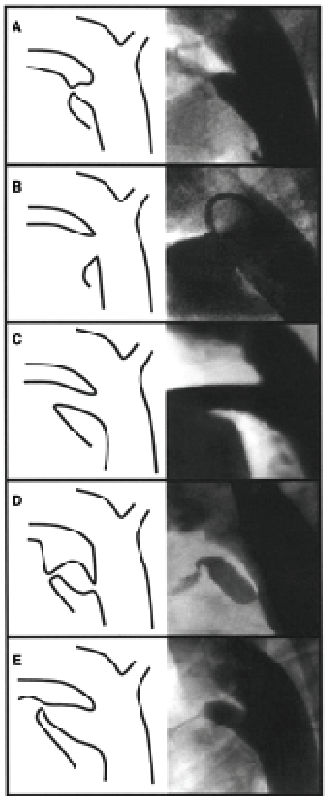

Figure 3. Variations in PDA configuration illustrated with the classification of Krichenko et al. The configurations are sketched on the left, and examples of lateral angiograms for each type are on the right. A, Type A ("conical") ductus, with well-defined aortic ampulla and constriction near the pulmonary artery end. B, Very large type B ("window") ductus, with very short length.C, Type C ("tubular") ductus, which is without constrictions.D, Type D ("complex") ductus, which has multiple constrictions.E, Type E ("elongated") ductus, with the constriction remote from the anterior edge of the tracheaking by Krichenko A, Benson LN, Burrows P, Moes CAF, McLaughlin P, Freedom RM. Angiographic classification of the isolated, persistently patent ductus arteriosus and implication for percutaneous catheter occlusion. Am J Cardio 1989;63:877-880.

With in-utero fetal circulation, the unexpanded lungs receive about 5-8% of the blood entering the pulmonary artery, with preferential flow through the patent foramen ovale into the systemic circuit. The ductus serves as the predominant exit route for circulation passing through the right ventricle and pulmonary artery. Approximately 55-60% of the systemic circulation passes throughout pregnancy from right to left through the ductus. The lower oxygen tension, coupled with higher levels of circulating placental prostaglandins, keeps the ductus patent.

Functional closure occurs within a few hours of birth in 90-95% of full term infants and anatomical closure is usually complete within 6-8 weeks. Folding of the endothelium and proliferation of the subintimal layers cause permanent closure, usually within a few hours to 4 days in 90-95% of full term infants, and 80-90% of premature infants (30-37 weeks gestation), as part of the adaptation to extrauterine life and declining pulmonary artery pressure[5]. More specifically, the functional closure rate is 42% at 24 hours; 78% at 40 hours; 90% at 48 hours; and 100% at 96 hours[9]. Thereafter, closure may occur later in life at a 0.6% per year rate[9]. The major stimulus for closure is the increased oxygen tension brought about by breathing, where oxygen increases the

synthesis of ATP, triggering smooth muscle contraction within the ductus. The anatomic closure begins at the pulmonary artery and progresses towards the aorta. Occasionally, a ductal aortic diverticulum or bump remains. Prematurity or immaturity contributes to the persistent patency or delayed closure of the ductus. This may be related to immaturity of the smooth muscle within the duct, or the inability of the immature lungs to clear the residual circulating prostaglandins or increase oxygen tension. Bilateral ductus although rare has been reported several times in the literature[7,10].

Campbell[11] studied the natural history of PDA, and concluded that the incidence of patent ductus after 1 year is 0.6% and that the annual mortality with PDA increases at 0.49% per year for patients aged 2 to 19 years and up to 1.8% per year for patients 20 and older, and 30% of them die from congestive heart failure. Other causes of death include pulmonary hypertension and endocarditis. Overall mortality is > 30% by 40 years of age and >60% by 60 years of age. The immediate postnatal pulmonary artery hypertension renders the PDA asymptomatic as it effectively limits the left to right shunt through the ductus. With subsequent declining pulmonary artery pressure after birth, the volume of blood flowing left to right through the ductus increases, leading to a haemodynamically significant shunt. Closure begins at the pulmonary end, with functional closure preceding anatomical closure.

Although failure to close is pathophysiological, continued patency is essential for a variety of congenital heart defects that have pulmonary or systemic flow dependent on the PDA for initial survival. With continued patency of the ductus and a decrease in pulmonary vascular resistance to below the level of systemic vascular resistance, blood flows from the aorta into the pulmonary artery through the ductus, resulting in a left-to-right shunt. The degree of shunting is determined by ductal resistance i.e. ductus diameter, length, and tortuosity. Flow continues through systole and diastole into the lungs, to the left atrium, the left ventricle, and back into the aorta. This results in an increased volume load on the left atrium and left ventricle, with an increase in left ventricular stroke volume that is proportional to the size of the ductus. The increased left ventricular stroke volume, and the central runoff from the aorta into the pulmonary artery results in a widened pulse pressure.

Over time the pulmonary vascular bed changes vary with regards to increased pulmonary vascular resistance and resultant pulmonary arterial hypertension (PAH) or Eisenmenger's syndrome. The morphological changes include arteriolar medial hypertrophy with intimal proliferation and fibrosis. With narrowing or obliteration of arterioles and capillaries, the pulmonary vascular resistance, (PVR) increases[2]. A PVR < 10 Wood units/m2 is usually reactive to vasodilators, whereas >15 Wood units/m2 is usually irreversible, and a relative contraindication for repair[3].

Clinically, Kozik et al[9]. classifies the hemodynamic impact of PDA on 3 factors: size and length that is directly proportional to the diameter, and inversely proportional to the length; the systemic resistance (SVR) and pulmonary resistance (PVR) ratio; and blood viscosity with low viscosity increasing the shunt fraction. They further postulate 5 pathophysiological scenerios : 1. Left to Right (L/R) shunt, non restrictive, with no significant Qp/Qs, and no PAH ; 2.L/R shunt, non restrictive, with significant shunt Qp/Qs, but no PAH, and low PVR; 3. L/R shunt, non restrictive, with significant Qp/Qs, PAH, but low PVR; 4. L/R shunt, (non restrictive), non significant Qp/Qs, but PAH and increased PVR; and 5. R/L shunt, low Qp/Qs, and suprasystemic PVR[9].

The present review highlights a variety of surgical procedures available for interruption of the ductal shunt. PDA dependent congenital heart defects for pulmonary or systemic flow are not discussed. The PDA is generally closed or addressed in those patients at the time of the palliative or total correction of the associated lesion(s).In addition, in depth medical management, and interventional treatment of PDA will not be discussed.

Therapeutic Background

Surgical efforts to interrupt the PDA began with Monroe's description of PDA ligation in infant cadavers in 1888[12]. Streider, in 1937, reported an unsuccessful PDA closure result. The operation of ligation was successful, but the patient died postoperatively from aspiration[12,13]. Cardiac surgery progressed with the first successful PDA closure on August 26, 1938, when Gross ligated the PDA of a 7 year old girl at Boston Children's Hospital[14]. He subsequently modified the technique of closure, dividing the PDA instead of ligation. PDA was the first congenital heart condition to be addressed surgically, and the first to be intervened percutaneously. However there is evidence that Emil Karl Frey, in 1938, from Germany also successfully ligated a PDA in a 14 year old female[15].

Interventional efforts began in 1967 when Porstman used a polyvinyl alcohol foam plug to close a PDA percutaneously[16]. In 1971, Rashkind

successfully closed a neonatal PDA using this approach[17]. Recently, both VATS and Robotic hemoclip occlusion has gained popularity in some centers[18,21].

Presently, with the many options available, there is considerable controversy with regards to the intervention that is optimal, be it medical, interventional, or surgical, taking into account the age, size and morphology of the PDA, clinical status, associated anomalies, cost, effectiveness, reproducibility, incidence of residual shunt, access or availability of care, and early/long term results.

Treament

Neonates

Medical Management

The PDA can be closed pharmacologically with inhibition of prostaglandin synthesis, the most frequently used drug being indomethacin and Ibuprofen. It has been shown to close 90% of PDAs successfully[22,25]. Mature infants and those treated later are less likely to respond. In full term infants, it is rarely beneficial. A schedule of three doses of 0.1 to 0.2 mg/kg IV every 12 to 24 hrs has been widely advocated. The ductus often closes before the second dose is given, so some have used echocardiographic surveillance to limit the length of the indomethacin course with no obvious adverse effect on closure rates. There is potential to limit unnecessary drug exposure in infants in whom the ductus has effectively constricted after the initial dose[23]. Conventional treatment of congestive heart failure (fluid restriction, diuretics, digoxin, ACE inhibitors) is marginally effective and only delays appropriate management. Administration of indomethacin even when the PDA is asymptomatic and very early administration of ibuprofen in the first 3 hours of life have been associated with improved outcomes in terms of decreased incidence of persistence of ductal shunt[24].

Prophylactic therapy is initiated within 24 hours of life irrespective of the status of ductus. If there is evidence of patency of the ductus (even if there are no clinical signs) then 4th, 5th, and 6th doses of indomethacin (0.1 mg/kg at 24 h intervals) are given. The echocardiogram is repeated after the 6th dose. In infants > 28 weeks with a birthweight >1,250 g the recommendation is 3 doses of 0.2 mg/kg; 2nd dose 12 h after the first, and the 3rd dose 24 h after the 2nd. In those with a birth weight between 1,000-1,250 g. the recommendation is 1st dose of 0.2 mg/kg; 2nd dose 12 h later, at 0.1 mg/kg; and 3rd dose 24 hrs after the 2nd dose at 0.1 mg/kg.

In cases where gestation is <28 weeks at birth with an infant weighing <1000 gm, 3 doses are recommended, 1st at 0.2 mg/kg, 2nd at 0.1 mg/kg (24 h after the first dose), and the 3rd at 0.1 mg/kg (24 h after the 2nd dose). With a patient weighing <1250 gm the recommendation is 0.1 mg/kg intravenously at 6 to 12 postnatal hoursand every 24 hours for further two doses.

Prophylactic ibuprofen in premature neonates includes one dose of ibuprofen lysine at 10 mg/kg intravenously followed by 5 mg/kg per dose intravenously at 24 and 48 hours of age[24].

Surgery

Surgical closure is recommended in the neonatal period if ductal closure is not achieved with medical regimens, especially in the presence of a hemodynamically significant shunt, persistent heart failure, or mechanical ventilator dependence[6].

Early surgical closure in preterm infants carries low surgery related mortality and morbidity[26]. The basic surgical procedures in neonates include ligation, division, or hemoclip. As noted, surgery is generally reserved for those premature or full term infants for whom prostaglandin inhibitors are contraindicated, or those who have failed medical therapy. Based on retrospective analysis, some authors have recommended surgical ligation for low birth weight (LBW) neonates. However, meta-analysis of pooled data has not shown any benefit of first line surgical ligation over medical therapy. In several randomized controlled trials, the rate of pneumothorax and retinopathy was higher with earlier surgery, but the incidence of necrotizing enterocolitis (NEC) was lower[23].

At present, the consensus is that surgery is effective and appropriate in symptomatic neonates who fail medical management, when medical treatment is not available, or when medical treatment is contraindicated[26,29].

Mandhan et al.[26] reviewed infants that underwent surgical ligation when indomethacin failed or was contraindicated. The mean gestational age was 25 weeks, and mean weight 837 g. The average age and weight at operation were 14.1 days and 881.79g., respectively. Postoperative complications occurred in 10 patients, which included intraoperative bleeding[6], pneumothorax[1], left vocal cord paralysis[1], lymphatic leak[1], and injury to left phrenic nerve[1]. There was no mortality related to surgical closure of PDA.

Jaillard et al.[27] studied the short and mid-term effects of delayed surgical closure in 58 infants who failed medical treatment or had a hemodynamically significant patent ductus arteriosus: systemic arterial pressure less than

gestational age in mm Hg, heart failure, left atrial-aortic root ratio greater than 1.6, mean velocity in the left pulmonary artery greater than 0.6 m/s, and ductus arteriosus diameter greater than 3 mm. The Infants were divided into two groups: (1) the early group who had surgery before 21 days of life (n = 31), and (2) the late group who had surgery after 21 days of life (n = 27). Preoperative and postoperative criteria were compared between the two groups (i.e. gestational age, birth weight, hemodynamic, ventilatory, and echocardiographic [left atrial-aortic root ratio, mean velocity in the left pulmonary artery] parameters). Hemodynamic, ventilatory, and echocardiographic parameters were similar in both groups. The rate of bronchopulmonary dysplasia was similar in both groups. However, at 24 hours post operatively, median FiO2 was higher in the late group (28%) than in early group (21%). Full oral feeding was acquired later in the late group (57 days of life) than in the early group (37 days of life), and body weight at 36 weeks of post-conceptional age was higher in the early group at 1,800 g than in the late group at 1,607 g. Early surgical closure of the ductus arteriosus (< 3 weeks of life) was associated with shortened delay for full oral feeding and improved body growth when compared with late surgical closure (> 3 weeks of life).

Vida et al.[28] suggested that after 2 complete cycles of ibuprofen medical treatment, surgical ligation should be recommended given that there is a 25% increased incidence of bronchopulmonary dysplasia (BPD) with >2 cycles of medical treatment.

El Khuffash et al.[29], from Toronto Hospital for Sick Children, have nicely developed a protocol for ligating neonatal PDA's. They documented that changes in cardiopulmonary physiology occurs in up to 50% of of infants following ligation. This post ligation cardiac syndrome (PLCS) occurs 6-12 hours post ligation and is related to increased after load. PLCS is defined as systolic blood pressure below the 3rd percentile and requiring 1 or more inotrophic agents, and associated with respiratory failure. They developed criteria for triaging preterm infants for ligation based on 3 clinical categories, and objective ECHO criteria that included PDA diameter, pulmonary overcirculation, and systolic hypoperfusion. This subsequently reduced the incidence of PDA ligation by >50%. The development of standardized post operative care based on the judicious use of volume support, inotrophic drugs, and hydrocortisone, reduced the mortality and morbidity in these high risk neonates.

Children/Adolescents/Adults

The management of an asymptomatic or silent PDA continues to remain controversial as the shunt is usually haemodynamically insignificant and the only associated risk is that of endocarditis, which, although minimal, has been reported[30]. However, the American Heart Association recommends no endocarditis prophylaxis for a PDA[31].

Symptomatic treatment is initiated once the ductus becomes clinically evident. This minimizes unnecessary exposure to drugs, especially in more mature infants. Also these patients are advised treatment for underlying secondary pulmonary hypertension, or heart failure secondary to continuous left to right shunting. Severe pulmonary hypertension and increased fixed pulmonary vascular resistance (PVR >8U/m2), with or without lung biopsy, may not be alleviated by, or is a contraindication for PDA closure, and ultimately, may or may not be an indication for high risk lung or heart/lung transplantation[2].

Interventional closure of PDA' >3mm are presently treated with interventional devices (Nit-occlud coil or Amplatz occlude) in suitable candidates, or unless there is a contraindication or non-availability of institutional capability[32,33].

Operative Techniques
Approaches:
Thoracotomy
Left posterolateral transpleural approach[34,39]

Anesthetic management is important, in terms of IV access, intubation, monitoring, anesthesia, assessing and maintaining adequate ventilation with monitoring of EtCO2 during positioning and lung retraction, and judicious fluid administration. In infants and children a smaller uncuffed endotracheal (ET) tube with a small leak is preferred. Pulse oximetry is monitored in both the right hand and a lower extremity. An esophageal stethoscope can be useful to assess the presence and disappearance of the machinery murmur following ligation or division. A coarctation can sometimes be unmasked following PDA ligation, and reflected by a decrease in lower limb saturation.

The patient is placed in a right posterolateral decubitus position. A small curvilinear incision is made one fingerbreadth below the tip of the left scapula. The chest is entered through the 3rd or 4th intercostal space. A Finochietto rib spreader retractor is used. This retractor is available in various sizes and is made of stainless steel, titanium, or aluminum .The lung is retracted inferiorly and medially using damp gauze

sponges and two ribbon retractors or suspended on sutures clamped to the medial chest wall . The mediastinal parietal pleura and periaortic connective tissue is opened along the descending aorta with reflection medially, or along the medial hilum with reflection laterally, and suspended with interrupted stay silk sutures (figure 4). This allows the vagus nerve and its recurrent branch to be reflected within this tissue. The.incision is carried up to the origin of the transverse aortic arch, and the left subclavian artery is identified. The hemiazygos or left superior intercostal vein overlying the aorta is ligated and divided (this can be large in infant heterotaxy cases). Any evidence of chylous leak is immediately repaired with suture ligatures, and may be avoided with ligation of fatty connective tissue at the lateral base of the left subclavian artery. The anterior edge of the opened mediastinal parietal pleura is retracted with stay sutures to improve exposure of the PDA, and to keep the vagus and recurrent laryngeal nerve away from the dissection site (figure 5). Cautery is avoided in this area, and sharp dissection is recommended. It is stressed that the phrenic, vagus, and recurrent laryngeal nerves be identified, as well as the aortic arch and left subclavian artery. Nerve structures are not handled with instruments. Identification of the PDA is crucial. A palpable thrill and identification of the recurrent laryngeal nerve encircling the PDA are important, along with identification of the aortic arch and takeoff of the left subclavian artery. The tissue plane close to the aorta above and below the PDA is opened parallel to it. A blunt tip right angle clamp is placed under the ductus from below and advanced upward only when the dissection around the ductus is deep enough, and dissection is kept closer to the aorta than the ductus along the posterior aspect (figures 6, 7).

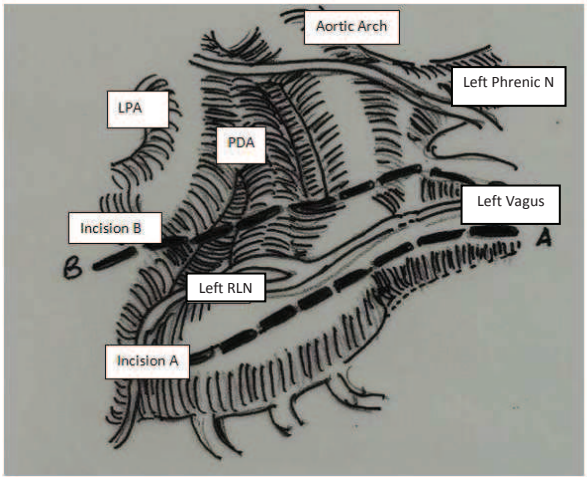

Figure 4. (34). Alternative incision of the mediastinal pleura along the aorta or hilum.

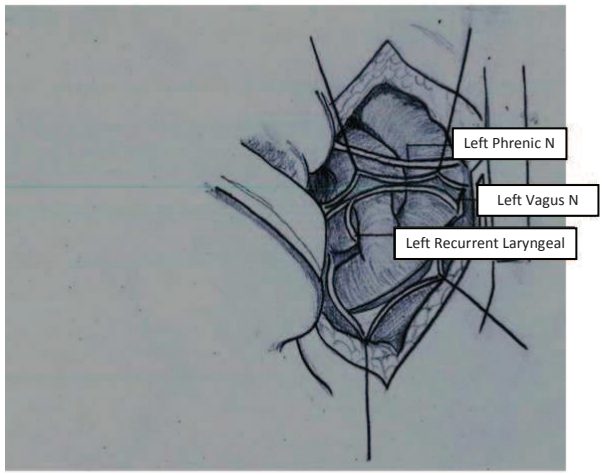

Figure 5 : Stay sutures are placed in the anterior edge of the mediastinal pleura, and the ductus encircled in a plane close to the aortic wall. Recurrent laryngeal nerve is in the pleural flap which is retracted medially over a moist sponge to protect the lung

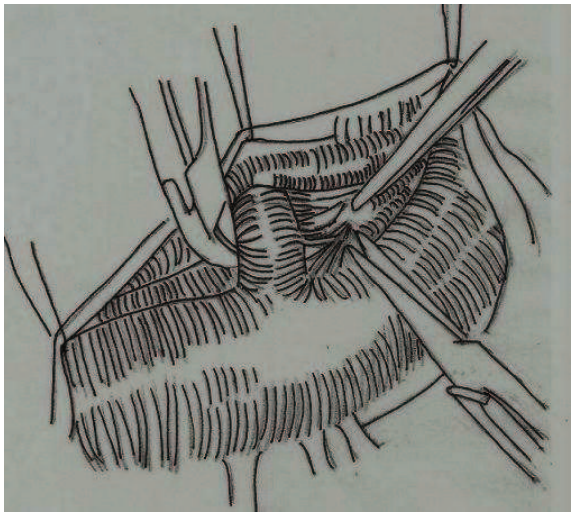

Figure 6 : Right angle clamp dissection around the ductus proceeding inferior to superior. Adhesive bands are cut sharply

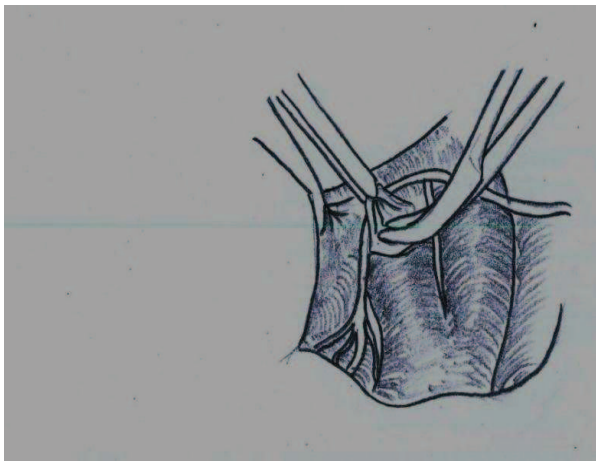

Figure 7 : Dissecting the lappet of the pericardium to ensure complete exposure of the ductus. Inadvertent opening will spill only clear pericardial fluid, not chyle

Doty[36] stresses that the right angle clamp jaws be opened gently with connective tissue within the clamp being grasped with forceps and completely excised. This creates a few back wall of the PDA ("the ductus maneuver"). This part of the procedure is most critical. Again, identification of the recurrent laryngeal nerve and the aorta are confirmed. Any confirmed or suspected chylous leaks are repaired immediately with suture ligation. The clamp is gently spread parallel to the ductus to improve exposure.
A test occlusion for 30 to 60 seconds is done with vascular forceps prior to formal interruption, be it ligature, division, or clipping. The disappearance of a palpable thrill, decreased murmur by esophageal stethoscope, maintenance of lower limb pressure, rise in diastolic pressure, decreased heart rate (Nicoladoni/ Branham sign), and maintenance of saturation (SpO2) in distal extremity are the usual parameters to evaluate prior to surgical interruption of the PDA.
Once hemostasis is achieved, as well as no evidence of chylothorax, the mediastinal pleura is closed, one chest tube placed, and the wound closed in layers. The chest tube is connected to under water seal drainage without suction. Alternately, if there is no lung injury, a chest tube is not inserted. The lung is inflated as the chest is closed, and a temporarily placed small red Robinson tube is removed after a sustained Valsalva maneuver.

Left small postero-lateral extra-pleural approach : Leon-Wyss et al. technique[40]

The patient is placed in the right lateral decubitus position, and the thorax is approached through a limited subscalpular incision, and a muscle splitting and superficial thoracic fascia muscularis incision made. The thorax is approached through the 3rd or 4th intercostal space. The periosteum is incised and the parietal pleura separated from the fascia using gentle blunt dissection by finger or kitner/peanut dissection. The aorta is exposed, the left hemizygos vein divided, the PDA dissected circumferentially, and the recurrent laryngeal nerve identified. The ductus is encircled with 1 or 1-0 silk sutures and then doubly ligated, leaving a space between the two sutures to allow additional ligation with titanium hemoclips, or placement of a third ligature. Haemostasis is achieved and any accidental tear of the visceral pleura is not repaired. If the pleura is inadvertently opened, then, at the end of the procedure, all the air is aspirated with a 12 to 14 French nasogastric tube, and it is removed when closing the subcutaneous tissue under a Valsalva maneuver. The chest is closed in layers without a thoracic drain.
This procedure has also been advocated by others, stressing the points that less dissection is required and the left recurrent nerve and chylous connections are better protected in their extrapleural course[41].

Methods of PDA Interruption:

Division

This is usually preferred in full term infants >2kg, children, and adults, when feasible, as it avoids the rare occurrence of recanalization, or aneurysm formation following ligation (figures 8,9). Spray[42] cautions that recanalization can occur in as many as 20-25% of ligation cases. The aortic end is occluded with vascular clamp close to the aortic wall. The pulmonary artery side is occluded next, close to the pulmonary artery wall, with a vascular clamp, carefully avoiding injury to the recurrent laryngeal nerve. Vascular clamps vary, the fine toothed Potts ductal clamps being preferred when available. In the case of a small ductus, a partial aortic occlusion clamp also can be used at theaortic end (figure 10). The ductus is then divided and the aortic end is oversewn first with a running over- and –over polypropylene (4-0 or 5-0 suture), or a double layer horizontal mattress and over-and-over suture[36]. The aortic closure is fashioned from posterior to anterior, then reversed for the second layer. The aortic clamp is removed slowly, then the pulmonary end closed in a similar fashion. Alternately, both ends are sewn following total or near total division and the clamps slowly released, the pulmonary clamp first. Both sutures are cut when hemostasis is achieved with sponge or hemostatic impregnated gauze compression.

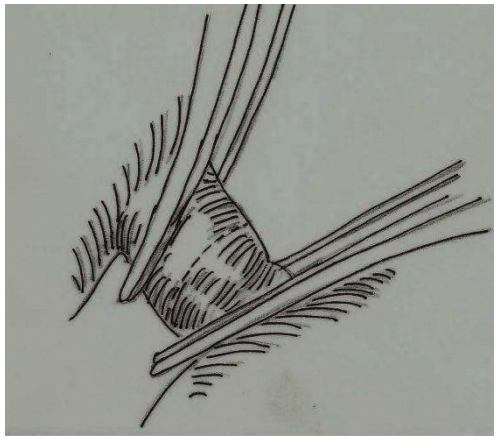

Figure 8 : Straight vascular clamps are applied and the ductus divided

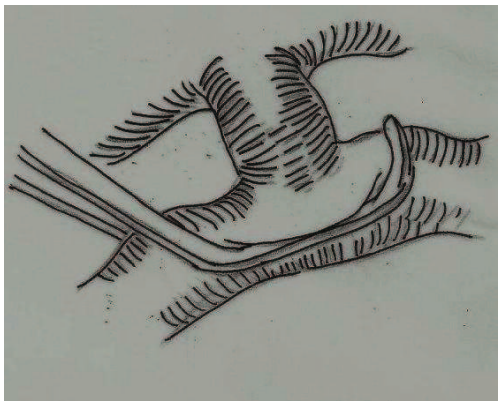

Figure 9 : Partial occlusion clamp at the aortic end to obtain more length for division

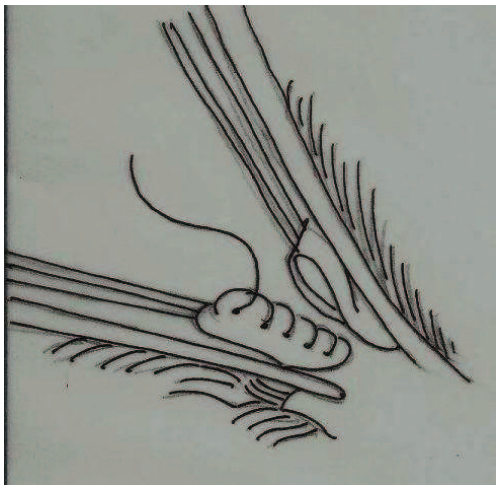

Figure 10 : Both ends of PDA are oversewn with running mattress sutures in one layer from inferior to superior and then reversed continuous over and over stitch in second layer.

Ligation with sutures[36,43,45]

Ligation is used primarily for preterm infants and newborns <2 kg (figures 12, 13). Thick ligatures of moist silk **(**sizes 2-0 to 1**)** are passed around the ductus, and the pulmonary end ligature tied first with both the index fingers in the plane of the ductus, given the ductus friability. The first throw should lie flat on the ductus (figure11,12). Sterile mineral oil can also be used to soften the silk ligature. Two to three ligatures are used. A short length of ductus is left between the 2 ligature technique to minimize recanalization. In the event of pulmonary hypertension, the aorta is temporary clamped above and below the ductus, the ductus ligated, and the clamps slowly and carefully released.

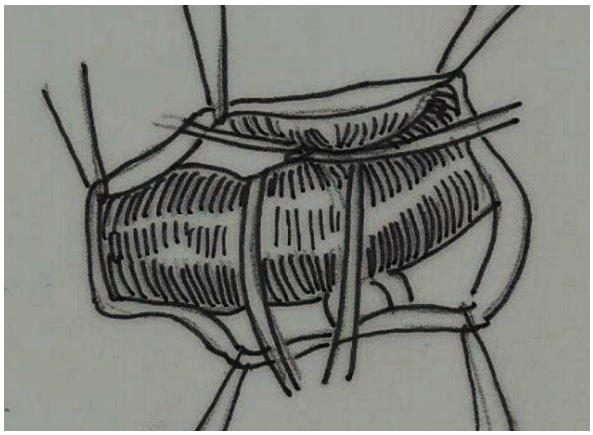

Figure 11 : Ligature to close pulmonary artery side first. Both index fingers should be deep in the chest in the plane of the PDA

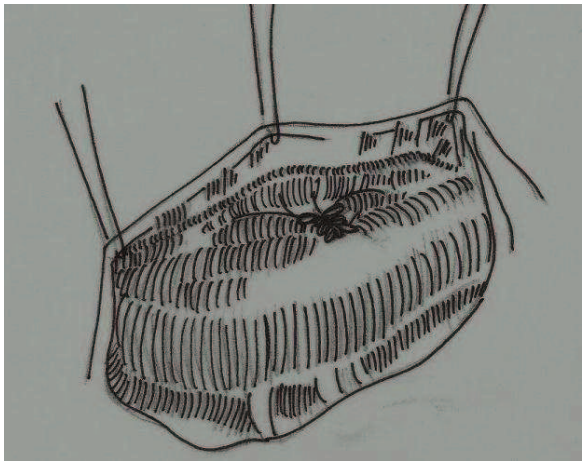

Figure 12 : Lumen of the ductus completely abolished with 1-3 silk ligatures

Hemoclip ligaclip, clip, or clipping[29,46]

An alternative technique of ligation in premature or term infants is hemoclip occlusion (figures 13,14). Dissection is limited to only above and below the ductus that runs either parallel or perpendicular to the aorta. The duct is usually friable (especially in indomethacin treated cases) and is not encircled. Two hemoclips are applied to occlude the ductus, but not too deep for fear of injury to the recurrent laryngeal nerve that runs posteriorly. Incomplete coverage of the ductus may cause bleeding from inadvertent tears in the ductus. The distal hemoclip ends can also cause bleeding from damage to the adjacent descending aorta, or the underside of the distal aortic arch. The hemoclip is usually titanium (5-9mm), as opposed to stainless steel or tantalum, since it is MRI compatible. It is stressed that incomplete coverage of the ductus can cause delayed bleeding, given the PDA friability, as well as leaving a residual shunt. Likewise, injury to the recurrent nerve or impingement on the left pulmonary artery should be avoided.

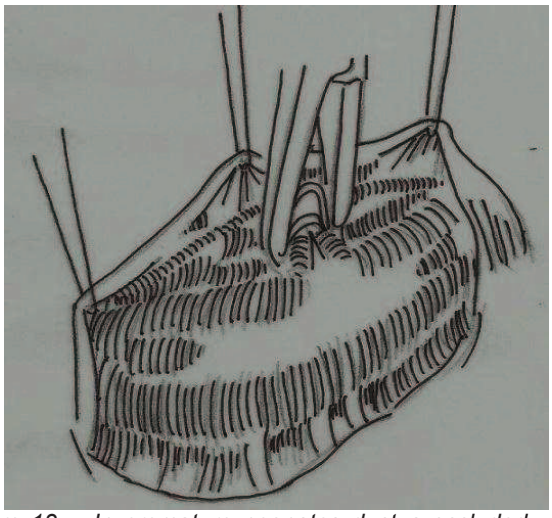

Figure 13 : In premature neonates ductus occluded with 2 small or medium sized titanium hemoclips. The recurrent laryngeal nerve is visualized and retracted medially

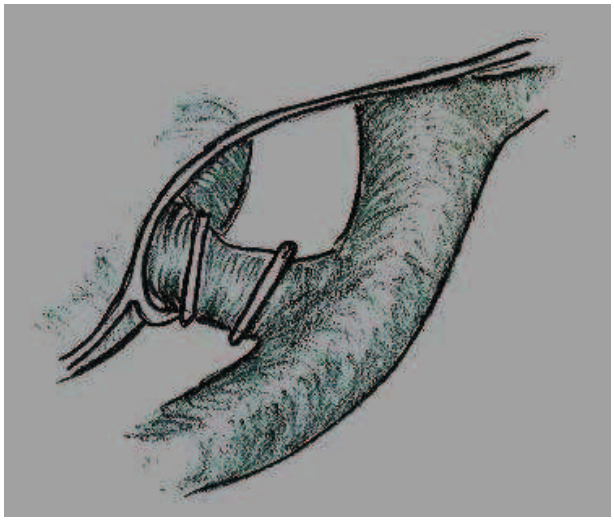

Figure 14 : Hemoclips in place

Vicente et al.[46] recommend the posterior extrapleural approach with the neonate in the prone position for PDA clipping. Under general endotracheal anesthesia the patient is placed in the prone position with the left hemothorax elevated 30°, and the left arm alongside the head so as to prevent the scapula from blocking the upper posterior ribs. A 2 cm incision is made between the tip of the scapula and the costovertebral bulge. The chest is entered through the fourth intercostal space and the ribs forced apart, being careful not to enter the pleural space. Gentle blunt extrapleural dissection allows the rib spreader to be positioned . Bimanual q-tip dissection completes the extrapleural access. Exposure is improved by manual ventilation and surgical retraction. The superior and inferior sides of the ductus aortic end are exposed with sharp dissection and one or two ligaclips are applied.

Ligation with polypropylene suture[37]

In older children the ductus may be wide and short making it difficult and dangerous to apply clamps and divide (figures 15). Adventitial stitches are taken using a double armed 5-0 polypropylene suture into the superior, inferior and anterior aspect of the ductus on both the ends. The aortic end is tied first followed by the pulmonary end, and finally a third suture ligature is placed in the middle of the duct to complete the ligation.

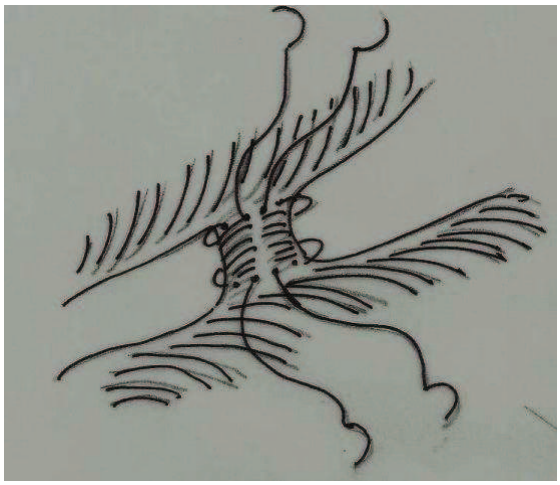

Figure 15 : Ductus obliterated using adventitial stitches with double armed 5-0 polypropylene sutures

Complex ductus

Pifarre et al. technique: aortotomy with a shunt[47]

In cases of a calcified, friable ductus, or in adult ductuses, the chest is entered through the bed of the left 5th rib which is sometimes resected, especially in adults, to allow better exposure. The distal aortic arch is dissected free and the ductus exposed. The left subclavian artery is isolated and tapes are passed. A purse string suture is placed in the distal aorta and tapes passed. For spinal cord protection, the patient is heparinized, and the subclavian artery and the distal aorta cannulated with a 9mm Gott shunt[48]. The aorta is clamped immediately proximal and distal to the ductus to exclude the intercostals vessels. The pulmonary artery (intrapericardial) is side-clamped using a vascular clamp near the ductus.Care is taken to avoid injury to the friable ductus while placing the clamp. The aorta is then gently opened longitudinally, and the orifice of the ductus exposed. Interrupted mattress sutures are passed through the aorta, and then through a Dacron (polyester fiber) patch, which is then secured and tied over the orifice of the ductus. The clamp is then removed and the patch examined for any leaks. The aortotomy is closed with double continuous row of sutures, the aortic clamps slowly removed, and flow re-established. The shunt is then clamped and removed.

Johnson/Kron technique: aortotomy without shunt[49]

A left thoracotomy through the bed of the fifth rib is made and the aorta is exposed above and below the calcified ductus that extends onto the aortic wall. Using systemic sodium nitroprusside (0.1-5mcgs/kg/minute) to lower systemic blood pressure, the aorta is clamped above and below the ductus since the calcification involves the aortic wall as well, adjacent to the ductus. A vertical aortotomy is performed allowing the ductus to be visualized. A No.5 Fogarty balloon catheter is placed through the orifice of the ductus and occluded (figure 16). The ductus is then closed from within using a circular piece of polytetrafluoroethylene (PTFE) patch with a running 4-0 polypropylene suture. The aortotomy is then closed and the clamps released. The total clamp time should not exceed 20 minutes.

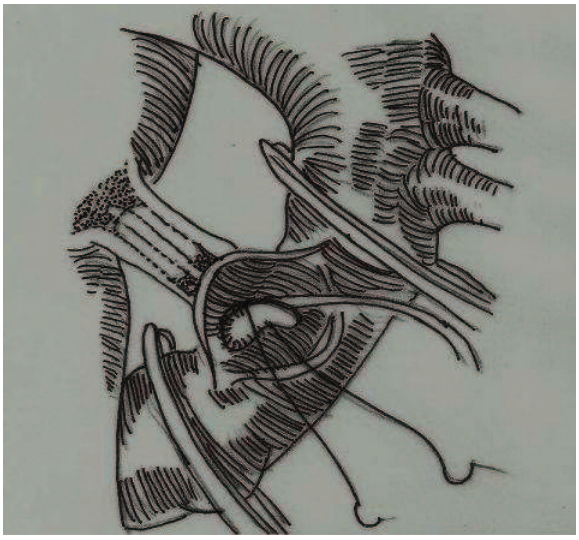

Figure 16 : Patch sewn in place avoiding calcified ductal orifice

Erdman et al. technique pledgetted suture[50]

In a calcified, friable ductus or one in adults, pledgetted sutures can be used safely to close the ductus. During dissection, and particularly while tightening the sutures, it is important to maintain controlled hypotension.

The chest is entered through the bed of the 5th rib. The distal aortic arch is dissected and tapes are passed around the aorta above and below the ductus. Great care is taken in dissecting the posterior wall of the ductus. Two mattress sutures of 00 silk are placed through two Teflon (fluorocarbon fiber) pledgets and placed on the superior and inferior surfaces of the ductus (figure 17). The sutures are tightened gradually until the ductus is obliterated. During dissection, and particularly while tightening the sutures, controlled systemic hypotension is maintained temporarily to 80 to 90 mmHg systolic with intravenous administration of sodium nitroprusside (0.1-5mcgs/kg/minute).

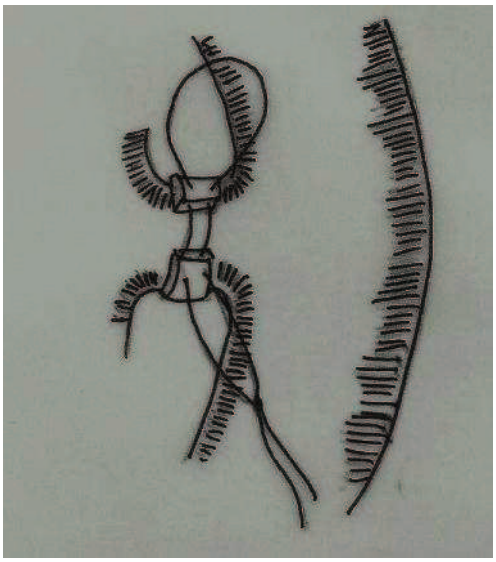

Figure 17 : Teflon (polytetrafluoroethylene) felt pledget compression of a broad fragile duct

Bell-Thomson et al. technique (Aortic cross clamping)[51] :

In older patients with a small, calcified ductus, pulmonary hypertension, aneurysmal dilatation of the PDA with calcification, or chronic endarteritis and resultant friable tissue, the chest is approached through a left postero-lateral thoracotomy and entered through the bed of the fifth rib. The parietal pleura is incised over the aorta and reflected medially with great care to protect the vagus and recurrent laryngeal nerves. The aorta is encircled with tapes above and below the ductus. The ductus is dissected further and deeper, and encircled with a 1 silk ligature. The aorta is cross clamped above and below the ductus and the arterial pressures monitored with a right radial line. Sodium nitroprusside is infused to maintain the systolic pressure below 80-90 mmHg (0.1-5mcgs/kg/minute). The ductus is then clamped, taking great care not to include the pulmonary artery. The ductus is then divided at the aortic end that includes a small rim of aortic wall. The aorta is closed with a 4-0 polypropylene suture, and the cross clamps removed. The aortic tissue on the ductus is then oversewn in a similar fashion, after which the ductus clamp is removed.

Lam technique : Intrapericardial approach[52]

In the presence of fibrous tissue on the ductus, as in redo cases where previous procedures have resulted in fibrous tissue around the ductus, the ductus is approached through the pericardial cavity.
The chest is entered through the left 4th intercostal space postero-laterally. The site of the ductus is identified by the presence of fibrous tissue from previous surgeries. The pericardial cavity is entered, and the main pulmonary artery and the proximal origin of the ductus are exposed. The aorta and the pulmonary artery are dissected away from each other keeping the plane of dissection close to the PA side and the tissue is pulled towards the aorta to avoid injury to the recurrent laryngeal nerve. Once the dissection is complete and allows compression of the ductus between the intrapericardial index finger and extra pericardial thumb, and is able to obliterate the thrill. Then two vascular clamps are placed across the ductus, keeping one blade of each clamp inside the pericardium. The ductus is finally divided and closed with a continuous mattress suture of 3-0 or 4-0 polypropylene suture.

Gold and Cohn technique[53]

A left sided posterolateral thoracotomy is made and the chest is entered through the 4th intercostal space. The mediastinal pleura is entered and dissected from the aorta, ductus and the pulmonary artery. The pulmonary artery is mobilized, and the ductus and adjacent area is palpated to identify any calcific areas. Two curved atraumatic vascular clamps are then placed on the ductal side of the pulmonary artery in such a way that the calcific areas are avoided and there is enough space for division and suturing (figure 18). The cuff between the clamps is divided and the ends are oversewn.

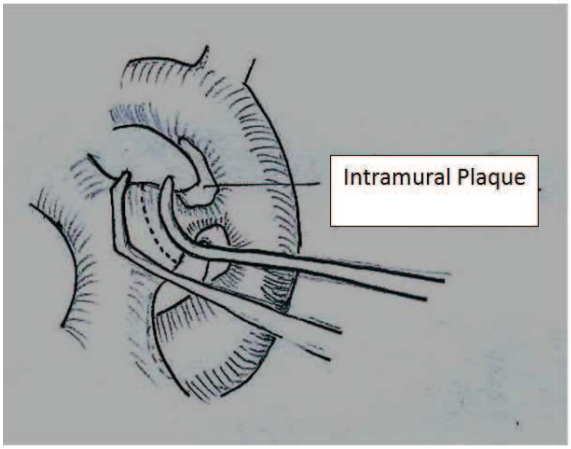

Figure 18. Vascular clamps on the pulmonary side of the duct leaving a cuff for division. The clamps avoid the area with palpable plaques.

Stejskal and Stark technique Left chest with Cardiopulmonary Bypass (CPB)[54]

A left thoracotomy approach utilizing short term clamp and repair, Gott shunt, left heart bypass or total cardiopulmonary bypass can be utilized for complex PDAs, especially in adults where there is concern to preserve or protect spinal cord function. Via a left postero-lateral thoracotomy the chest is entered through the 4th intercostal space. After heparinization the distal aortic arch is cannulated proximal to the left subclavian artery. The pericardium is opened anterior to the phrenic nerve. The main pulmonary artery is cannulated and the cannula gently directed through the pulmonary valve into the right ventricle. The distal pulmonary artery and left pulmonary are dissected to allow individual cross clamping. CPB is then initiated. The patient is cooled to 30-32 degrees Celsius. The proximal and distal aorta?the main pulmonary artery, and the distal left pulmonary artery proximal and distal to the PDA are clamped. Via a vertical aortotomy the PDA is visualized and repaired, followed by aortic closure.

Other Thoracotomies
Muscle sparing left thoracotomy: Karwande/ Rowles technique[55]

A left posterolateral incision from the midaxillary line, around the tip of scapula to the midposition of the spine and the scapula is made. The auscultatory triangle bounded by the latissimus dorsi, trapezius, and scapula is identified. Connective tissue between the two muscles is divided and the latissimus muscle mobilized, taking care to minimize subcutaneous dissection. The third or fourth interspace is entered between the trapezius and latissimus dorsi. The remaining procedure is the same as given above, depending on the choice of technique for ductus occlusion.

Right Thoracotomy[56]

An isolated right sided patent ductus arteriosus with a right or left sided aortic arch, in the absence of intracardiac defects, is very rare. In cases of an isolated right ductus, a right thoracotomy is performed, and the ductus is identified after retracting the lung, and identifying the pulmonary and the aortic end of the ductus, which is treated as previously described. In cases requiring repair of coexisting intra cardiac lesions, the chest is approached through a median sternotomy.

Minithoracotomy:

Demirturk et al.[41] have reported minithoracotomy with extrapleural clipping of the ductus in 24 high risk patients in congestive failure with no surgery related mortalities. Four deaths were due to sepsis and bleeding diathesis. The results showed that extrapleural clipping could be a better less invasive alternative to the conventional closure methods.

Median sternotomy

Median sternotomy is reserved for complex situations, or in combination with repair of associated congenital defects. For aneurysms, redoes, or, in adults with a calcified, short or large ductus, or suprasystemic pulmonary hypertension, a median sternotomy approach should be considered. From this approach a decision to employ CPB can be determined. With CBP on standby, and if the PDA can safely be dissected and repaired without CPB, then ligation or division is employed. If CPB is required, the patient is heparinized, cannulated, and placed on CPB. The surgeon must decide from a variety of techniques to employ. Perfusion considerations include normothermia, moderate cooling to 28-32 degree Celsius, deep circulatory arrest (DCA), as well as myocardial protection strategies beating heart, short term induced electrical ventricular fibrillation, or cardioplegic arrest. Prevention of systemic air embolism is a major concern with the open techniques. This requires adjunctive measures, e.g. the judicious use of Trendelenberg positioning, lung ventilation, aortic venting, or flooding the operative field with CO2 gas.

If the ductus is short, and encased by adhesions due to prior procedures, or a ductal aneurysm is present, the ductus should be repaired on cardiopulmonary bypass (CPB). If small, the ductus orifice can be closed with ligature, or with pledgetted mattress sutures of 3-0 or 4-0 polypropylene suture. If larger, and in most adults, the defect requires opening the pulmonary artery with repair from within. This requires primary closure, or closure with an autologous or bovine pericardial patch, a woven polytetrafluoro-ethylene, or a Dacron or Gore-Tex patch using a running suture or interrupted horizontal pledgetted sutures of 4-0 or 5-0 polypropylene suture.

Before CPB[34,35,37,38]

With repair of concomitant coexisting intracardiac lesions, a median sternotomy is performed. The pericardium is opened longitudinally and marsupialized or suspended to the skin with traction silk sutures. The aorta and pulmonary artery are separated, and the right and left pulmonary artery branches are dissected to the hilum, if better identification is needed (figure 19). Using gentle traction on the adventitia, the aorta is retracted towards the right, and the proximal main pulmonary artery (MPA) is retracted inferiorly and to the right. The PDA is identified, and the left pulmonary artery (LPA) is identified running parallel and to the left. The PDA is dissected circumferentially with a right angle forceps, then clamped, divided, and oversewn or ligated with 2-0 braided silk suture before institution of CPB[35]. It is important not to ligate before CPB if the PDA is the only blood supply to the pulmonary circulation[38].

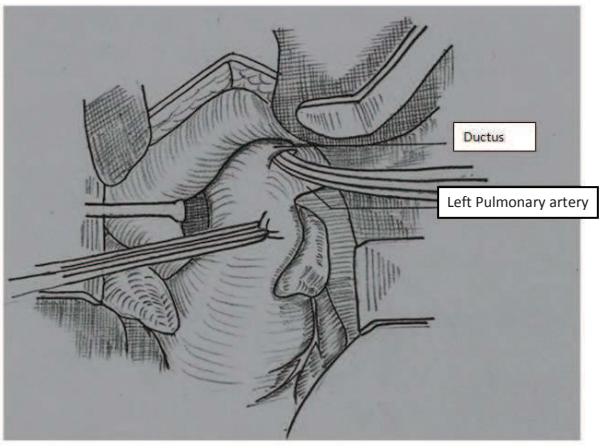

Figure 19. Median sternotomy approach to PDA. Important to identify the left pulmonary artery to the right and inferior to the PDA by retracting with forceps the main PA to the right. Avoid cautery in distal PDA dissection near recurrent nerve.

On CPB:

i) Through an aortotomy: When the ductus is short, calcified, infected, or with dense adhesions through a previous thoracotomy, the patient is placed on CPB. If the lungs become flooded and the right heart distended, then the PDA is finger compressed, avoiding compression of LPA, systemic flow decreased, and the aortic end of the ductus occluded with a straight vascular clamp and the ductus divided after reducing perfusion flow, and the patient cooled to 32- 34 degrees Celsius. The aortic end is oversewn, or patch closed if large, first and the clamp removed. The pulmonary end is then inspected, and either primarily closed or augmented with a small patch of autologous pericardium to avoid stenosis of the left pulmonary artery[37]. Alternatively, core temperature is reduced to 25 degrees Celsius, systemic flow to 0.5liters/meter 2sq, the heart mechanically fibrillated if not done spontaneously, both cava snared, and closed from within with lower flow or a balloon placed distally to occlude flow from the opened PDA[37].

ii) Through a pulmonary arteriotomy: When there are more complex adhesions, a ductal aneurysm, pseudoaneurysm, or when encircling the ductus is difficult, the ductus is closed from inside the pulmonary artery on low flow cardiopulmonary bypass (0.5L/m2/ minute). The pulmonary artery branches are snared to prevent lung flooding through the PDA. A small vent is placed through the right superior pulmonary vein into the left atrium. The patient is cooled to 20-22 degrees Celsius, the heart mechanically fibrillated, or with aortic cross clamping and antegrade cardioplegic arrest, caval snares snugged, the MPA opened, and the ductus inspected. The head is lowered and care is taken to maintain a blood level in the pulmonary artery to prevent air entry to the aortic arch. If the opening is small it can be closed using interrupted mattress sutures under intermittent low flow bypass. Alternatively a balloon tipped catheter can be used to reduce flow through the ductus as the sutures are placed.

With severe pulmonary hypertension or a fragile and calcified ductus low flow bypass and perfusion hypothermia are employed[57]. An inflated Foley balloon catheter or Fogarty catheter occludes the orifice of the ductus in the aorta thus preventing air from entering the aorta (figures 20, 21). It also provides a dry operative field. In this technique temporarily reduced pump perfusion and accelerated suction are useful. The patch can be mounted on a Fogarty catheter and a purse string suture placed around it. The tip is then introduced into the aorta through a pulmonary arteriotomy. The balloon is inflated in the aorta. The catheter is pulled up gently and can be slanted in any direction for convenience of the procedure. The patch is then sutured and secured. After the completion of the procedure the Fogarty catheter is removed and the purse string suture tied.

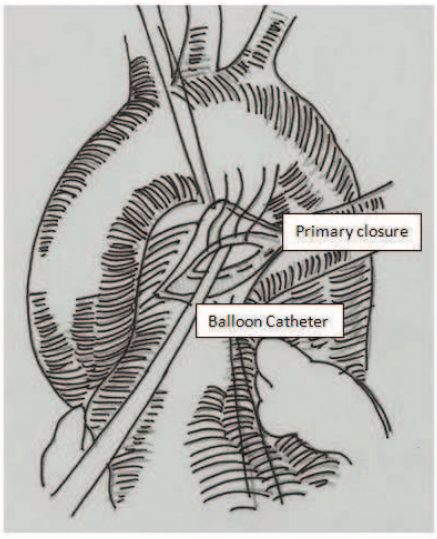

Figure 20 : Primary open PDA closure with interrupted sutures without bolsters, and with occluding balloon catheter in place through the PDA.

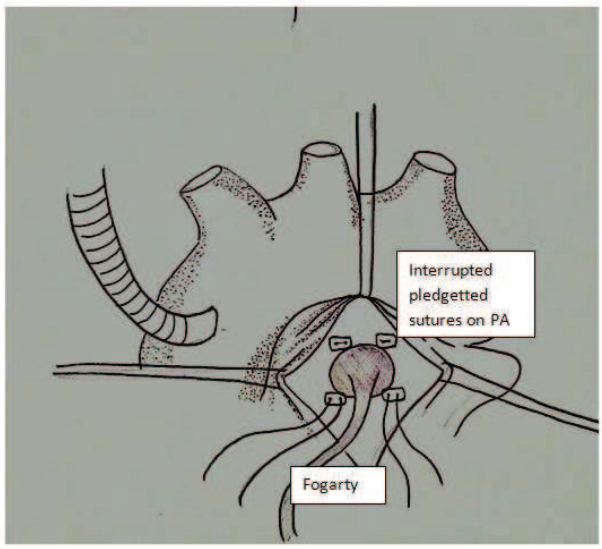

Figure 21 : Interrupted sutures on the pulmonary artery side of the ductus, with Foley or Fogarty balloon in place.

Omari et al.technique[58]

When available and feasible, intraoperative TEE is used to visualize the ductus. Cardiopulmonary bypass is maintained at normothermia with a beating heart. The flow is stopped temporarily as the distal main pulmonary arteriotomyis opened with a short vertical incision. A 16F Foley catheter is inserted into the patent ductusand inflated and full cardiopulmonary bypass resumed. Pledgeted 4-0 polypropylene sutures are passed fromone side of the defect to the other, without damaging the balloon. Pumpflow is again decreased and the Foley catheterremoved. The sutures are tied and secured.If a patch is required, pledgeted sutures areplaced around the circumference of the orifice and then up throughthe patch.

Inaba et al.technique[59]

Cardiopulmonary bypass is established with aorto- bicaval cannulation,and the procedure is performed on beating heart under normothermia. The main proximal PA is opened vertically without reducing flow. A 14F Foley catheter isinserted through the PDA interrupting the flow of blood from the aorta (figure 22) and a purse string suture of pledgeted CV-4 Gore-Tex is placedaround the orifice of the ductus. The last stitches of each needle are taken outside thePA and tied, just after removing the Foley catheter. Thisresults in complete cessation of shunt flow. Another pledgeted 3-0 polypropylene suture is placed sothat the orifice of the PDA is between the 2 pledgets. Each stitch comesfrom inside the PA and below the orifice, to outside the PAand above the orifice. The pulmonary artery is then closed and the ductus occlusion is confirmed by TEE.

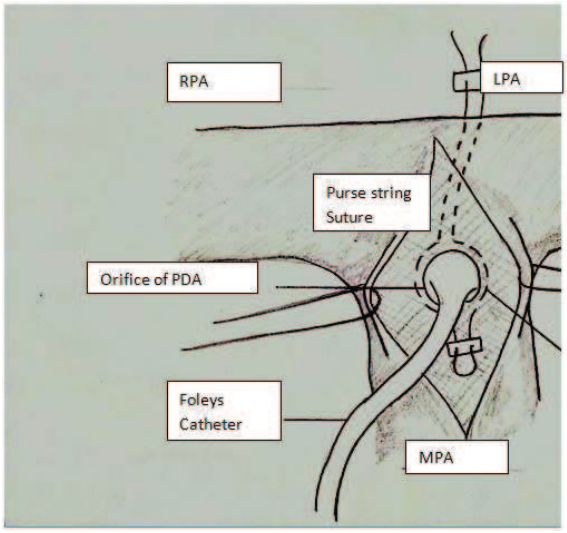

Figure 22 : An alternative circumferential primary occluding technique with purse around the orifice of the PDA

Toda et al. technique[60]

CPB is established and mild hypothermia (32 -34 degrees Celsius) achieved. Cold blood cardioplegia is infused through the aortic root. Alternately, electrical ventricular fibrillation or with the heartbeating is used. The proximal pulmonaryartery is vertically opened. Direct or patch closure isperformed using the balloon occlusion method (figure 23). A 20-F or 24-F inflated Foleycatheter is used for occlusion, with Dacron patch, Gore-Tex, or autologous or bovine pericardium availablefor patch closure. With this technique the balloon is through thecenter of the patch after purse-string suture using a 4-0 polypropylenewhen patch closure is performed. The patch is sutured on theorifice with a 3-0 or 4-0 polypropylene.When direct closure is performed, a 3-0 polypropylene is used. No reduction of pump flow is performed during this maneuver.

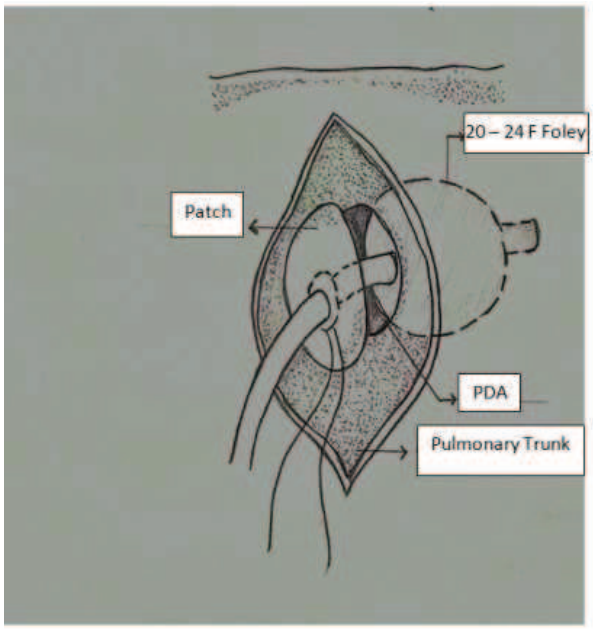

Figure 23 : Ductus closed from within the pulmonary artery with occluding catheter placed through the patch into the PDA and aorta

Discussion

While the focus of this review has been surgical management of the PDA, other salient features such as indications, unusual situations, and surgical complications warrant mention. Consensus regarding management of a ductus is lacking and therefore the clinical practices across the world vary a great extent[40]. Nevertheless, the primary indication for treatment is the presence or persistence of a PDA beyond one year of age, given that < 1% per year close spontaneously beyond that age[9]. In neonates, failure of medical treatment is the primary indication. In children the indications are controversial. In the asymptomatic or silent PDA, the fear of endarteritis is the primary indication. A silent ductus is defined as being present by ECHO only[61]. As endarteritis is now rare, prophylactic antibiotics are no longer recommended[31]. Despite this, there is data to suggest that it remains a concern, causing pulmonary valve endocarditis secondary to its presence[62]. It is recommended that the silent PDA should be closed in all cases[63]. In adults, specific guidelines have been proposed[64].

The operative mortality of isolated PDA closure is <1%. The operative surgical complications range from 5-10%. They include bleeding, chylothorax, nerve injury (phrenic, vagus, recurrent laryngeal with resultant diaphragmatic injury, left vocal cord paresis or paralysis, especially in infants <1 kg.),

recanalization, aortic dissection, creation of aortic coarctation, inadvertent ligation of the aorta or left pulmonary artery, pseudoaneurysm, endarteritis, or gastric distension secondary to vagus nerve traction and resultant gastroparesis[4,34,39]. Wound sequelae include scoliosis, and migration of the wound scar which occasionally occurs on the left lateral breast with the growth of the female child.Khonsari and Sintek[39] highlight other technical points to avoid pitfalls. These include: judicious use of cautery near the recurrent nerve to avoid injury; never clamp the ductus itself, rather adhere to the pulmonary or aortic tissue; gentle temporary forceps compression of the ductus – if bradycardia or decreased saturation and systemic pressure then release and confirm the anatomy; flooding of operative field with ductus closure performed on CPB to decrease possibility of air emboli; awareness that clips may cause bleeding or not totally close the ductus; and, in case of severe bleeding during left chest approach, then open the pericardium and clamp main pulmonary artery, as well as proximal and distal aorta, then proceed to close the ductus.

When a large PDA arises proximal to the left pulmonary artery, sweeping into the descending aorta and appearing to be the arch, the ductus overlies the arch and hides it from view. Sometimes a large distal left pulmonary artery can be misinterpreted as the ductus[65]. To prevent inadvertent ligation of the left pulmonary artery the structures are dissected further and the anatomy clarified. It should be stressed that the recurrent laryngeal nerve encircles the PDA. If recognized, the actual ductus is divided, and the distal left pulmonary artery is then reconstructed with a direct anastomosis[65].

Endarteritis of the PDA is a serious concern, especially in developing countries. During the preantibiotic era the average age of death of patients with a PDA was 36 years and infective endoarteritis was the most common cause of death, accounting for 45% of deaths[66]. In today's era of antibiotics the risk of bacterial endocarditis has significantly decreased. A retrospective study from 1984 to 1996 of all the patients' records in Great Ormond Street Hospital found only 2 cases of endocarditis associated with PDA[54]. Although the incidence of bacterial endocarditis is reported to be 0.45%per patient per year, it is one of the more serious complications of a persistent ductus. This is especially true in developing countries or emerging economies. Sadiq et al.[66] from Pakistan noted a recent incidence of 4.8 patients/1,000 hospital admissions in children <16 years of age admitted to a pediatric cardiology referral center.

In an antibiotic treated and cured PDA, surgery is usually performed within 6-8 weeks thereafter. When antibiotic therapy fails, urgent surgery may be necessary. Vegetations continue to grow and can embolize to the lungs and systemic circulation. Surgery is performed via a median sternotomy with cardiopulmonary bypass. After isolating the left pulmonary artery between a proximal vascular clamp and vascular loops placed on the primary branches of the left pulmonary artery to isolate the vegetation, the ductus is then resected with a segment of adjacent pulmonary artery wall to which the vegetation is attached. Subsequently, safe reconstruction of the aorta and pulmonary artery under direct vision is performed.There have been reports of direct ligation or division of the ductus in such cases but the potential disadvantages include embolization of the vegetation, rupture of a friable ductus, bleeding, or incomplete elimination of the infected area[30].

PDA aneuryms are rare, being seeing primarily in older patients, or following previous repair, in which case they are usually pseudoaneuysms. Diagnosis of a ruptured aneurysmal ductus is challenging and entails a strong suspicion in an infant with an intrathoracic mass[67,69]. ECHO, CT, MRI, or cineangiocardiogram confirms the diagnosis, and urgent surgery is usually warranted. The most common pathogenic findings are interruption of the internal elastic membrane and aneurysm formation, with focal proliferation of endothelial cells leading to mounds of disarranged intimal structures[69].

Other unusual or rare situations are encountered with PDA's, especially for interventional devices. Caution is advised for transcatheter interventional approaches, especially with large PDA's and pulmonary hypertension. Other reported complications include: hemolysis; left pulmonary artery protrusion, occlusion, or stenosis; and pseudocoarctation of the aorta secondary to device protrusion[70]. Surgical backup should always be available.

There has been recent interest in evolving palliative staging procedures for duct dependent congenital lesions. Subsequent operations involve removal of the ductus arteriosus stent[71]. This creates a challenge, since migration into the LPA, or obstructive neointimal proliferation requires meticulous and cautious dissection to remove the stent without injury to adjacent structures.

Blunt thoracic aortic injury is a life threatening problem. Diagnostic evaluation and confirmation includes clinical suspicion, CXR, spiral CT, trans thoracic (TTE) or transesophageal (TEE) ECHO, and selective use of aortography. In difficult cases, the judicious use of both can separate out a traumatic subintimal tear or pseudoaneurysm from an aortic ductus bump or remnant[72,73].

Currently, endovascular aortic stenting has become popular for a variety of aortic conditions[74]. There is scant literature related to its application for a ductus. Roques et al.[75] described an elderly high risk patient who underwent a stent graft exclusion of the PDA with positioning in the aorta in front of the PDA. This may become widely applied, given the attendant risks of CPB and interventional deployment of a device in large PDA's i.e >4mm.

In those elderly patients with a calcified patent ductus arteriosus, where the surgical risk of interruption is high owing to the propensity for breakage of the calcified ductus during manipulation, the current established practice is to percutaneously place a PTFE membrane covered stent in the descending aorta, thus excluding the ductus from the circulation. The same technique also holds good for simultaneously addressing the combined issues of a PDA with associated severe coarctation of aorta[76].

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