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Pulmonary Artery Banding

Pulmonary artery banding (PAB) is a palliative surgical technique used as an initial surgical intervention for cardiac defects characterized by left-to-right shunting and pulmonary overcirculation. As many centers have demonstrated improved outcomes with primary corrective surgery in a neonate with congenital heart disease, the use of pulmonary artery banding has significantly decreased, but PAB continues to be an option in certain subset of patients. Currently, the mortality of PAB is low 3-5%, and is related to improved operative techniques, better patient selection, optimal timing of intervention, and better patient management.

23.1 Objective of PAB & Pathophysiology

The important objective of PAB is to reduce excessive pulmonary blood flow (PBF) and protect the pulmonary vasculature from medial hypertrophy and irreversible (fixed) pulmonary hypertension.

PA band is also used to prepare and "training" of the left ventricle in patients with D-transposition of the great arteries who are evaluated for a delayed arterial switch procedure.

The important goals of PAB are improved hemodynamic performance and clinical improvement of patient, with complete resolution of signs and symptoms of congestive heart failure or latter should be medically manageable. The cardiomegaly and pulmonary vascular resistance should decrease. Pulmonary artery banding affords protection to the pulmonary vasculature against fixed irreversible pulmonary hypertension secondary to pulmonary overcirculation and elevated pulmonary artery (PA) pressure.

Congenital heart defects with left-to-right shunting result in pulmonary over - circulation due to low pulmonary vascular resistance. In the acute setting, this leads to pulmonary edema and CHF in a neonate. Within the first year of life in

an infant, unrestricted pulmonary flow and elevated pulmonary pressure can lead to hypertrophy of the medial layer of pulmonary arterioles resulting in fixed pulmonary hypertension.

Pulmonary artery banding creates a narrowing of the main pulmonary artery, decreases blood flow to the branch pulmonary arteries, and reduces PBF and pulmonary artery pressure.

In cardiac defects with left-to-right shunting, the restriction of PBF decreases the shunt volume, consequently improving both the systemic pressure and cardiac output.

A reduction of PBF decreases the total blood volume returning to the LV or the systemic ventricle and decreases volume load of the ventricle, thus improving ventricular function.

Interatrial communication:

Cardiac defects in which adequate systemic oxygen saturation is maintained by mixing of the systemic venous and pulmonary venous blood (i.e., TGA), PA band is not tolerated if a restrictive communication exists between the two atria. To ensure adequate mixing of blood at the atrial level, a balloon atrial septostomy or an atrial septectomy is performed before proceeding with pulmonary artery banding.

23.2 Indications

Both, the common and rare conditions requiring PAB are broadly grouped into two categories as discussed below:

23.2.1 Those with Pulmonary Overcirculation and Left-to-right Shunting

Following patients require reduction of pulmonary blood flow (PBF) as a staged approach to more definitive repair:

1. Multiple muscular ventricular septal defects (VSDs) with a "Swiss cheese" septum that is technically difficult to repair in a neonate or requires a large ventriculotomy.
2. Unbalanced atrioventricular canal defects in which the LV is hypoplastic, but the potential exists for the biventricular repair.
3. Single or multiple VSDs with coarctation of the aorta or interrupted aortic arch (it may be controversial for a staged procedure).
4. Cardiac defects (D-TGA) that require a homograft conduit:
   - *D-TGA with sub pulmonic stenosis:*

     It requires the Rastelli repair. PAB may allow a time for growth of the patient and permits placement of a larger conduit, at the time of repair, and potentially increases the longevity of the conduit and freedom from reoperation.
   - *D-TGA & pulmonary stenosis (PS)* requires Rastelli procedure and placement of a right ventricle (RV)-to-pulmonary artery (PA) conduit. If a staged repair is elected, PAB is not done because of already decreased pulmonary blood flow. Instead, a systemic-to-pulmonary shunt is performed.
5. Single ventricle defects in neonates that are associated with increased PBF.

The patients who have single ventricle physiology and pulmonary over - circulation (i.e., tricuspid atresia with unrestrictive VSD, unbalanced AVC defect, and double inlet LV) should undergo PAB in the first 1-2 months of life

to avoid irreversible pulmonary hypertension that may complicate or preclude a subsequent Fontan procedure.

23.2.2 D. TGA Patient &Training of the Left Ventricle

It is performed as a staged approach to the arterial switch procedure.

1) Initial late presentation or diagnosis of D-TGA in infants older than 1 month, often requires preparation of the LV for arterial switch.
2) D-TGA patient requiring preparation of the LV for arterial switch, following a previous Mustard or Senning procedure, with the development of right ventricular failure.
3) L-TGA that requires preparation of the LV prior to the arterial switch procedure.

23.3 Issues with PAB & Specific Situations

23.3.1 D Transposition of Great Arteries (D-TGA) & PAB

Most of the patients with D-TGA should undergo an arterial switch procedure within the first few weeks of life. However, some with D-TGA and an intact ventricular septum may not undergo an early arterial switch procedure because of active infections, coexistent noncardiac diseases, or a delay in diagnosis.

During the past, patients who did not undergo early an arterial switch procedure were treated by the Mustard or Senning procedure because of rapid involution of the left ventricular myocardium which precluded arterial switch.

Current strategy of pulmonary artery banding and concomitant systemic-to-PA shunt resulted in preservation of the LV and reversal of any attenuation of the myocardium, leading to successful arterial switch later in infancy.

23.3.2 Post Mustard / Senning RV Dysfunction

PAB is also used in TGA patient who develops right ventricular dysfunction after the Mustard or Senning procedure. The PAB is required for a longer period (12 months are less) in this setting than the preparation of LV for arterial switch in infants who present > one month of age. The high prevalence of significant neo-aortic valve insufficiency is noted in these patients who successfully undergo the arterial switch procedure.

23.3.3 Corrected Transposition (SLL) & L Transposition & PAB

Patients with L-transposition or physiologically corrected transposition of the great arteries may present with systemic RV (right ventricular) dysfunction (the ventricle giving rise to aorta). PAB is used to retrain the LV in preparation for a double switch operation.

23.3.4 Reactive Pulmonary Vascular Disease & PAB

The patients with elevated but *reactive pulmonary hypertension*, from long-standing left-to-right shunting may carry significant morbidity and even mortality after an immediate surgical repair. PAB and pulmonary vasodilator therapy may drop pulmonary vascular resistance, in some of these patients, and subsequently respond more favorably to surgery.

23.3.5 Truncus Arteriosus

PAB is avoided. In truncus arteriosus type I, MPA (main pulmonary artery) is very short and does not allow banding without impingement on the right pulmonary artery (PA) or the origin of the MPA from the truncal artery. In truncus arteriosus types II and III, bilateral pulmonary artery banding effectively reduces PBF, but studies have shown that balancing of PBF to the

right and left lungs is extremely difficult, and subsequent complete repair is complicated by bilateral PA stenosis requiring extensive reconstruction.

23.3.6 Hypoplastic Left Heart Syndrome

A hybrid approach of stenting the ductus arteriosus and bilateral pulmonary artery banding may achieve an effective short-term palliation. But balancing the systemic and pulmonary blood flow to achieve near-equal distribution of blood flow to the right and left lungs can be extremely difficult, and PAB is considered only in the high-risk patients.

23.3.7 Subaortic Obstruction

In cardiac defects with a single ventricle in which the aorta arises from an outflow chamber (e.g., double inlet left ventricle & tricuspid atresia with TGA), there is a potential for development of significant subaortic obstruction after PAB.

The risk of subaortic obstruction further increases if these lesions are also associated with aortic arch anomalies. *PAB is contraindicated in either the presence of subaortic obstruction or in patients who are at high risk for such an obstruction.*

The ventricular hypertrophy that develops in a response to PAB may cause rapid progression of sub aortic obstruction, leading to progressive biventricular hypertrophy, and both ventricles will be having outflow tract obstruction.

The subaortic obstruction also develops after PAB, from conal hypertrophy or from hypertrophy of an abnormally positioned moderator band in patients with the single ventricle and a subaortic outflow chamber.

23.3.8 Damus-Kaye-Stansel Procedure

Cardiac defects with a single ventricle in which the aorta arises from an outflow chamber, the patients for risk of developing subaortic obstruction are identified preoperatively by:

1. A gradient > 15-20 mm Hg, at an outlet foramen with a pullback catheter, on cardiac catheterization.
2. Doppler echocardiography: The outlet foramen area index < 2 cm^2/m^2.

Pulmonary artery banding is contraindicated in the above setting. Instead, these patients should undergo the Damus-Kaye-Stansel procedure and a systemic-to-pulmonary artery shunt to get adequate pulmonary blood flow (PBF) with protection of the pulmonary vasculature.

23.3.9 Fontan & Bidirectional Cavopulmonary Anastomosis

The development or persistence of subaortic stenosis post-PAB, can adversely affect the outcome of future Fontan procedures in patients with the single ventricle physiology through the development of ventricular hypertrophy, poor ventricular compliance, and subendocardial ischemia.

If obstruction occurs later in the course after banding, either resection of the obstruction or Damus-Kaye-Stansel procedure with or without a concomitant Fontan procedure is done. Bidirectional cavopulmonary connection may be performed early if anatomy and physiology are appropriate.

23.4 Surgical Technique

The standard surgical approach for (PAB) is through an anterior left thoracotomy in 2nd or 3rd interspace (for an isolated procedure). Through a left lateral thoracotomy, the chest is entered through the 3rd or 4th intercostal space if PAB is to be performed in conjunction with a coarctation or an interrupted aortic

arch repair. The median sternotomy is used if intracardiac procedures (e.g., atrial septectomy) requiring cardiopulmonary bypass are indicated or for TGA.

The MPA and aorta are exposed, and the band is prepared for placement. Various banding materials are available such as Teflon, umbilical tape, etc. The umbilical tape is broad enough to minimize the risk of eroding through the PA wall, but it can still be passed easily through a silastic snare for use as an adjustable band. The estimated band circumference is marked on the umbilical tape with fine sutures according to the Trusler's formula. Most importantly, these estimates of band circumference are used simply as guidelines, and that the final tightness of the band is ultimately determined by a surgeon, using blood gas and PAP (pulmonary argratery pressure) measurements at the time of surgery.

PAB circumference (based on Trusler's formula):

The estimated circumference for noncyanotic non-mixing lesions (e.g., ventricular septal defect) is 20 mm + 1 mm/kg body weight.

Single ventricles in which the Fontan procedure is planned, an intermediate circumference of 22 mm + 1 mm/kg body weight is acceptable.

Mixing lesions (e.g., D-transposition of the great arteries with VSD), the formula is 24 mm + 1 mm/kg body weight.

The site of band placement is selected in the mid portion of the MPA trunk. In most patients, the length of main pulmonary artery (MPA) is adequate to allow placement of the band in the mid portion, without impingement on either the coronary arteries, pulmonary valve proximally, or the branch pulmonary arteries distally. The right pulmonary artery (PA) arises slightly more proximal on the MPA than the left PA. The right PA also arises at more of an acute angle. Both of these factors, increase the risk of right PA impingement by a distally placed band. Dissection is performed in the adventitia between the aorta and the MPA, and it is

limited to prevent proximal or distal band migration. The MPA is handled very carefully because it often is dilated, thin-walled, and susceptible to injury.

The band is first passed through the transverse sinus to encircle both the aorta and MPA. The aortic end of the band is then carefully delivered between the aorta and the MPA through the previous site of dissection (see Figure 23.1). The marked sites on the band are identified and aligned with each other on the anterior wall of the MPA. The band is snared with a short segment of #8 or #10 polyethylene tubing and fixed with medium hemoclips. A felt or pericardial pledget is placed beneath the band between the end of the snare and the MPA wall to prevent injury to the artery from the snare. The pledget and band material are then anchored to the MPA adventitia to prevent band migration.

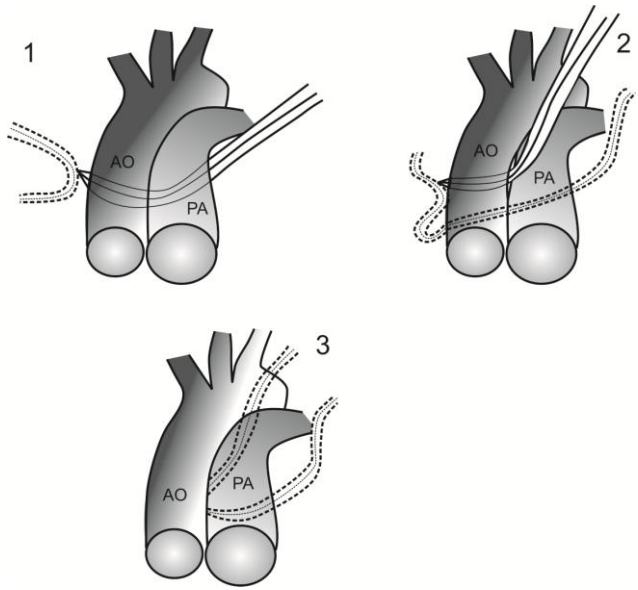

Figure 23.1 *Diagram depicting the technique of placing the pulmonary artery band. 1). One end of a tape is first passed through the transverse sinus by a clamp behind the ascending aorta (AO) and the main pulmonary artery (PA). 2). The other end of the tape is retrieved through a hole created by the dissection between AO and PA. 3). Both ends of the tape encircle the main pulmonary artery.*

23.4.1 Adjustable Band

Patients may benefit from placement of an adjustable band that can be easily and quickly tightened or loosened, both at the initial procedure and during subsequent interventions.

a) It is useful in postoperative patients who exhibit dynamic changes in cardiac output, pulmonary vascular resistance, and systemic vascular resistance.

b) It is particularly helpful in patients with AV valve regurgitation such as complex AV canal defects. The acute increase in the afterload that accompanies pulmonary artery banding, may exacerbate AV valve insufficiency. Staged tightening of the band is usually well tolerated and allows improvement in insufficiency by decreasing the ventricular volume overload.

c) It benefits the patients with significant lung disease (e.g., pneumonia, pulmonary edema, and atelectasis). These patients develop severe arterial oxygen desaturation with pulmonary artery banding, but may tolerate gradually increasing band tightness as the pulmonary process resolves.

23.4.2 Assessment of Tightness of PAB

Measure during operation the following:

1. Proximal PA pressures (PPA) and distal PA pressure (DPA).
2. Systemic arterial blood pressure (SBP).
3. Systemic arterial oxygen saturation (SaO_2) (by a blood gas and pulse oximetry).

Appropriate tightness of PAB should produce the following:

1. DPA pressure 30-50% of SBP (0.3 to 0.5 of SBP).
2. SaO_2 of 85-90% with an FIO_2 of 0.5 (50%).

3. SaO_2 of 75-80% may be acceptable with a single ventricle.

4. SBP increase by 10-15 mm Hg.

Failure to achieve above levels in defects, requiring mixing of blood at atrial level (i.e., single ventricle and TGA), suggests inadequacy of an interatrial communication. In such patients, atrial septectomy or atrial septostomy is indicated as an additional procedure.

Circumferential banding of a dilated pulmonary artery can acutely lead to internal infolding of the arterial wall. Later resorption of the infoldings and remodeling of the arterial wall restore a greater internal cross-sectional area. These infoldings resorb with time, restoring a smooth wall and greater internal cross-sectional area of the lumen, greater PBF, and thus a looser band. The incisional pulmonary artery banding has produced a more stable band gradient over a time with fewer requirements for subsequent tightening. It has also eliminated the complication of band migration distally and impingement on the branch pulmonary arteries.

23.5 Postoperative Management

The overall clinical assessment of a patient is critical after PAB.

Careful attention is directed to note changes in systemic blood pressure, heart rate, oxygen saturation, and overall cardiac function.

Hypotension, bradycardia, and ischemic electrocardiographic changes, all indicate an excessive band gradient and imminent cardiac failure or arrest.

The advantage of an adjustable PAB allows for rapid loosening of the band with a hemoclip remover in the ICU, if necessary.

23.5.1 Fluid Balance and Blood Volume

Require meticulous attention to ensure adequate volume to maintain optimal cardiac output without a fluid overload. Improved left ventricular output and hemodynamic performance following PAB allows for diuresis and gradual resolution of CHF.

23.5.2 Inotropic Support

Inotropes are often required to maintain adequate cardiac output.

23.6 Follow-up

Patients with PAB should undergo systematic follow-up, both clinically and by imaging studies, for earliest recognition and management of any complications and any issues raised with PAB.

23.6.1 Imaging Studies

These are performed on follow-up or during the postoperative period to evaluate the physiological effects of PAB.

23.6.2 Doppler Echocardiography

It makes the evaluation of PAB at the bedside. It provides an accurate assessment of band tightness, band gradient, band position, and overall cardiac function. Any impingement or stenosis of the branch pulmonary arteries can also be observed with this study.

23.6.3 Cine Magnetic Resonance Imaging

It is also useful as a noninvasive method of evaluation of PAB.

23.6.4 Cardiac Catheterization

Rarely, the direct measurement of PA pressure and band gradient is necessary. The patients with pulmonary overcirculation usually require PAB for 3-6 months, and should then undergo more definitive repair of the cardiac defect. However, if rapid and severe right ventricular hypertrophy develops earlier, definitive repair should be considered to prevent long-term right ventricular dysfunction.

Patients with D-TGA are assessed to note the “readiness" of the LV before the arterial switch operation. Both the quantitative measurements of LV mass index and qualitative assessment of ventricular septal geometry are monitored by serial echocardiogram. Left-to-right septal bowing is an indication that the LV can generate near-systemic pressure. Left ventricular preparation is usually accomplished within 7-10 days after PAB.

23.7 Complications of PAB

23.7.1 Stenosis of the Branch Pulmonary Arteries

The impingement or stenosis of one or both of the branch pulmonary arteries may occur though the RPA is involved in most cases. Asymmetric vascular markings between the right and left lungs on chest x-ray suggests the diagnosis, and is confirmed by echocardiogram and by radionuclide lung perfusion scan which estimates fractional pulmonary blood flow (PBF) to each lung. Early recognition of the branch PA stenosis should allow a revision of the pulmonary artery. If significant stenosis is uncorrected, it can lead to underdevelopment of the involved lung with alveolar hypoplasia. Limiting the dissection of tissue between the aorta and the main pulmonary artery (MPA), and fixing the band with sutures on adventitia of the proximal MPA reduce the risk of this

complication. Use of incisional pulmonary artery banding technique also prevents distal band migration.

23.7.2 Ineffective PAB

Loss of the band murmur and recurrence of CHF after pulmonary artery banding suggests loosening or erosion of the band. Either a loose band at the original procedure or later disruption of the band, or erosion of the PA results in this complication. The pulmonary vascular disease with irreversible pulmonary hypertension may potentially develop due to ineffective band.

23.7.3 Erosion of the Pulmonary Artery

Erosion of PA seems to occur with an increased frequency when narrow banding material is used although it can occur with any material**.** It is heralded by loss of the band murmur and gradient. The erosion of the band results in scarring and fibrosis of the vessel around the band site. The scarring of the vessel prevents the life-threatening bleeding from rupture of the vessel, but hemolytic anemia and local thrombus formation may occur.

23.7.4 Pseudoaneurysm of PA

Localized infection and erosion of the band precedes this complication, and is heralded by loss of the band murmur and gradient. Imaging studies and echocardiogram demonstrate an enlarged mediastinal mass shadow consistent with PA pseudoaneurysm. The diagnosis of PA pseudoaneurysm mandates urgent surgical intervention. Repair is performed on cardiopulmonary bypass with a patch repair of the MPA using glutaraldehyde-treated autologous pericardium.

23.7.5 Pulmonary Valve Dysplasia

If PAB is placed too proximal on the MPA, it may distort the pulmonary valve and ultimately create dysplastic changes in the pulmonary valve leaflets. This complication is devastating if PAB is performed in preparation for an arterial switch procedure because the pulmonary valve becomes the neo-aortic valve.

23.7.6 Myocardial Ischemia or Infarction

Proximal placement of the band can lead to obstruction of the coronary blood flow by direct impingement, usually of the circumflex coronary artery. Anomalous origin of coronary artery may also increase the risk of this complication. This complication is avoided by placement of the band > 15 mm distal to the pulmonary valve cusps.