

Pulmonary Hypertension in the Adult with Congenital Heart Disease

What the ICU Bedside Nurse Needs to Know

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Introduction

- The normal pulmonary vascular bed is a low pressure, low resistance circuit.
- Pulmonary hypertension (**PHT**) is defined:
 - Elevated mean pulmonary arterial pressure (PAP) ≥ 25 mm Hg at rest or > 30 mm Hg during exercise with a normal pulmonary capillary wedge pressure (< 15 mm Hg)
 - Elevated pulmonary vascular resistance (PVR) index (≥ 3 Wood units x meter squared)
- PHT is a disease characterized by elevated PAP which can lead to right heart failure and death.

At risk population:

- PHT has multiple potential causes including idiopathic PHT, lung diseases or hypoxia, chronic pulmonary artery (PA) vessel thromboembolic, drugs, toxins and multiple systemic or metabolic disorders. Causes may include acute respiratory distress syndrome, acute LV dysfunction, obstructive sleep apnea or following cardiac or thoracic surgery.
- Congenital and acquired heart disease can contribute to the development of PHT.
 - **Unrepaired lesions that may present with PHT in the adult** with congenital heart disease:
 - Increased pulmonary blood flow (PBF) under high pressures (such as large ventricular septal defect, truncus arteriosus, AV Canal, large ductus arteriosus or complex unrepaired lesions)
 - Increased PBF under low pressures (unrepaired adult atrial septal defect)
 - Pulmonary venous outflow obstruction (pulmonary vein stenosis, chronic mitral stenosis)
 - Systemic ventricular dysfunction, severe (may be related to longstanding severe aortic valve stenosis with LV hypertrophy and associated LV diastolic dysfunction, and elevated pressures)
 - Patients with residual PHT despite surgical repair of the congenital defect
 - Patients with palliative aortopulmonary shunts- Blalock Taussig shunt, central shunt (Waterston/Potts)

Pathophysiology:

- Untreated congenital heart defects (CHD) with persistent systemic to pulmonary artery (left to right) shunts expose the pulmonary vascular bed to increased pressure and flow, which can lead to progressive pulmonary arteriopathy and severe vascular changes.
- This injures the pulmonary vasculature resulting in thickening of the pulmonary endothelium and narrowing of the vessels. Left untreated, this leads to further increases in pulmonary vascular resistance (PVR)
 - This progresses to elevated right ventricular (RV) pressure & resulting RV failure, with systolic & diastolic dysfunction.
 - Poor RV function can result in low cardiac output
- Patients who have undergone single ventricle staged cavopulmonary procedures (Fontan or Glenn procedures) require low PVR for survival, since systemic ventricular preload is dependent on passive flow of systemic venous return into the lungs.
 - A moderate increase in PVR or PAP can cause *critical* alterations or failure of the Fontan or Glenn circulations, decreased left ventricular filling. This will manifest as low cardiac output.
- Left heart valvular or ventricular disease can cause PHT when the left atrial pressure is elevated creating a backward transmission of this pressure into the pulmonary veins, leading to increased PAP.
- Eventually in PHT the pulmonary vasculature can become severely damaged or “fixed” & unresponsive to vasodilators, **Eisenmenger’s syndrome**.
 - If a patent foramen ovalae, atrial or ventricular communication is present, ongoing PHT can lead to a bidirectional shunt or predominantly right to left intracardiac shunt. This shunt can maintain cardiac output but leads to hypoxemia and cyanosis.
 - Progressive right ventricular failure and premature death will occur.
 - The congenital heart lesion is inoperable in Eisenmenger syndrome.
- Additional triggers for development of PHT in CHD patients include hypoventilation, high altitude, restrictive or parenchymal lung disease and genetic predispositions such as Down syndrome.

Critical Thinking:

- Triggering events exacerbating PHT episodes
 - Hypoxia
 - Acidosis (metabolic or respiratory)
 - Cardiopulmonary bypass has been shown to result in endothelial cell injury, release of vasoconstrictor agents, impaired nitric oxide production and formation of microemboli and atelectasis which can further increase PAP and PVR.
 - Non-cardiac surgery (cardiac catheterizations)
 - Initiation of anesthesia
 - Respiratory infections
 - SUCTIONING – endotracheal, particularly in children
- **Goals** of PHT care include lowering PAP, decreasing PVR and RV afterload while maximizing RV function, ultimately improving cardiac output

- Care will focus on: Optimizing ventilation, improving RV function, sedation, treating pain, avoiding metabolic and respiratory acidosis, avoiding atelectasis, avoiding anemia, minimize energy expenditure needs.
- In PHT patients, acute elevations in PVR can lead to a “*crisis*” with acute right sided heart failure, with decrease in cardiac output, systemic hypotension, acidemia (metabolic) and right-sided heart ischemia.
- A PHT “*crisis*” can progress towards cardiovascular collapse and death.
- Operative or anesthetic interventions for an Eisenmenger syndrome patients require careful coordination.
- Air filters and/or air vigilance on all venous catheters due to right to left intracardiac shunts and risk for systemic embolization are required.
- Therapies used in PHT chronic treatment must be continued uninterrupted in the perioperative period to avoid potential for acute PHT crisis
- Vasopressor & inotropic support may be required in perioperative periods

Clinical Assessment

- Frequent, close examinations are important in evaluating for changes in patient’s condition, as well as ongoing response to treatment
- General constitution- pallor, cyanosis, edema, level of distress/acuity
- Vital signs
 - Heart rate: slow, fast
 - Rhythm- sinus, tachycardia, arrhythmia (chronic vs acute/new onset), ectopy (type, frequency)
 - Blood pressure: hypertension or late hypotension due to PHT “*crisis*”
 - Temp: fever can be manifestation of infectious process or low-cardiac output and leads to increased energy expenditure
 - Respiratory rate and effort
 - Oxygen saturation: must compare to patient’s baseline
 - A patent foramen ovalae may be present in PHT patient
 - Desaturation can indicate right to left intracardiac shunts
 - AVOID any air in IV lines
 - Systemic arterial desaturation will be present in Eisenmenger Syndrome
 - CVP: reflection of volume status & RV function. Goal in care includes finding the optimal RA/CVP which provides the best cardiac output.
 - High RA pressure may signal acute rise in PA pressure
 - Left atrial pressure (LAP): as RV volume and pressure load increase, the intraventricular septum shifts toward the left, limiting left ventricular (LV) filling and output.
 - Low LAP may signal the decreased pulmonary venous return seen in PHT crisis
 - End tidal CO2 monitor
 - An increase in arterial to ETCO2 gradient could signal a decrease in effective pulmonary blood flow
 - Neck- presence of jugular venous pulse with a large V wave
 - Jugular vein distension, evidence of increased CVP

- Reflects RV dysfunction
- Chest exam:
 - Increased precordial activity
 - Heart sounds (S1, S2), extra heart sounds (S3/gallop, S4),
 - Murmur prominent 2nd heart sound; holosystolic blowing murmur of tricuspid regurgitation, and murmur related to CHD
 - Lung sounds- coarse breath sounds associated with pulmonary edema, wheeze
 - Right ventricular heave may be present
- Abdominal exam: hepatomegaly , liver may be tender or pulsatile, ascites
- GU: urine color, volume
- Skin: cool peripheral temperature (low output), diaphoresis, turgor, color
- Extremities: capillary refill, perfusion- compare to central perfusion, peripheral edema
- Clubbing: due to chronic systemic arterial desaturation
- Eisenmenger syndrome:
 - Presenting symptoms include:
 - Dyspnea on exertion, hypoxemia, cyanosis, palpitations
 - Edema and fluid retention
 - Erythrocytosis secondary to hypoxemia
 - Ischemic chest pain due to right ventricular ischemia

Diagnostic Evaluation

- Chest x-ray
- EKG : may show signs of RV hypertrophy
 - Tachyarrhythmias can lead to decreased cardiac output, deterioration in Cardiac output (CO)
- Labs: CBC, electrolytes, coagulation studies, BNP, others as appropriate.
 - Polycythemia – related to chronic hypoxemia
 - Liver or thyroid disorders may be present
- Echocardiogram
 - Estimates RA/RV/PA pressures, tricuspid regurgitation, bowing of ventricular septum towards the LV, RV dilation and contractility
 - Diagnosis of CHD lesion
- Cardiac catheterization
 - *Definitive* assessment of hemodynamics (PVR, PAP vs. systemic pressure, cardiac output)
 - “Reactivity” or a response to pulmonary vasodilator therapies (nitric oxide, oxygen, Flolan, etc.) will result in lower PAP, drop in PVR
- Other: CT, MRI, lung perfusion scan,
 - pulmonary function tests, pulmonary embolism protocol
 - Six minute walk test – used to assess prognosis at baseline and treatment effects at follow up exams

Treatment:

- In critical presentation, PHT care will focus:

- Elimination of stimuli which further cause pulmonary vasoconstriction, PVR elevations
 - Hypoxia
 - Alveolar hypoxia (PaO₂ < 60 mmHg)
 - Acidosis (respiratory or metabolic)
 - Pain
- Treatments which promote pulmonary vasodilation & reduce PVR
 - Oxygen administration
 - Pulmonary vasodilators: Nitric oxide, sildenafil
- If the pulmonary pressures/vascular bed are responsive, the PA pressures may be decreased by:
 - Relative hyperoxia
 - Relative hypocarbia (arterial CO₂ of 32-35 mm Hg)
- Goal of care: Optimize RV function and thus provide sufficient LV preload and cardiac output.

- **Table 1: Strategies for Treatment of Pulmonary Hypertension**

AVOID:	ENCOURAGE:
Factors which raise PVR by pulmonary vasoconstriction	Factors which lower PVR by pulmonary vasodilatation
Hypoxia	Oxygen
Acidosis / hypercarbia	Alkalosis / hypocarbia
Agitation / Pain	<i>Sedation / anesthesia</i>
Excessive hematocrit	Normal to low hematocrit
Hyperinflation	Normal functional residual capacity
Atelectasis, hypoventilation	<i>Nitric Oxide</i>

Adapted from Wernovsky, published in Nieves, 2010

- Goal: *Early* identification & management of acute PHT episode versus crisis
- **Table 2: Pulmonary Hypertensive Event versus Pulmonary Hypertensive Crisis**

Condition:	PHTN Event	PHTN Crisis
Definition:	Acute rise in PAP with stable arterial blood pressure	Paroxysmal event where PAP systolic pressures match or exceed systemic pressures. May result in RV failure, fall in left atrial preload & systemic hypotension
Focus on close, EARLY detection of these signs:		
Heart rate	Elevated	Elevated- late bradycardia
Arterial blood pressure	Stable	Decreased

O2 saturation	Stable or decreased	Decreased(cyanosis) if R to L intracardiac shunting is possible
Central venous/ Right atrial pressure	Stable or elevated	Elevated
Left atrial pressure	Stable	Decreased
Cardiac output/SV02	Decreased	<i>Severely</i> Decreased
Serum lactate	Normal	Increased
** Systemic perfusion	Decreased	<i>Severely Decreased</i>

Adapted from Wernovsky, published in Nieves, 2010

- Treatment
 - Optimize ventilation
 - Low tidal volumes and low positive end expiratory pressures
 - Avoid lung hyperinflation, excessive or inadequate positive end expiratory pressure
 - *Oxygen* is a key component in PHT by causing pulmonary vasodilation, reducing PA pressure and improving cardiac output in any patient with PHT, regardless of the cause.
 - Avoid hypercapnia and acidosis because they further lead to pulmonary vasoconstriction
 - Exacerbation of PHT may result from endotracheal tube displacement, partial occlusion of the tracheal tube, inadequate ventilation, pleural effusions, lobar collapse and/or pulmonary infections.
 - Avoid hypercapnia and hypoventilation during weaning, extubation or sedation due to increase in alveolar hypoxia, further hypercapnia, and acidosis leading to exacerbation of pulmonary vasoconstriction
 - Avoid hypoxia, which can contribute to pulmonary vasoconstriction
 - Hyperoxygenate prior to & during suctioning procedure
 - Pulmonary vasodilators-assess effect on cardiac output (CO)
 - Optimize sedation, pain control
 - Consider sedation prior to noxious stimuli such as suctioning
- Optimizing RV (subpulmonary) ventricular function
 - Inotropic IV: Epinephrine, dopamine
 - Ino-dilators:
 - Milrinone
 - Dobutamine (at doses up to 5 mcg/kg/min can decrease PVR. Doses > 5-10 mcg/kg/min can provoke tachycardia).
 - Monitor central venous pressure/right atrial pressure (CVP / RAP) to identify value that provides optimal cardiac output
- Fluid balance: optimize preload. Note that both hypovolemia and hypervolemia can lead to suboptimal preload and worsen cardiac output

- Diuretic therapy
- Normothermia
- Treating cause: treatments for parenchymal lung disease, hypoxemia, sepsis, left ventricular dysfunction, acute thromboembolism, or other causes.
- Sinus rhythm to optimize cardiac output
- **Pulmonary vasodilators**
 - **Inhaled**
 - *Oxygen*
 - Nitric oxide (iNO)
 - iNO is a selective pulmonary vasodilator which is effective at low doses 2-20 parts per million (ppm).
 - iNO does not cause systemic hypotension.
 - Onset of iNO effect is 1-3 minutes, half-life: 3-6 seconds.
 - iNO therapy requires continuous infusion and cannot be interrupted even briefly for suctioning or transportation off the unit.
 - iNO must be weaned gradually
 - with careful initiation of other therapies which will promote pulmonary vasodilatation (such as oxygen), and avoiding stimuli which might provoke additional PHTN episodes.
 - A rebound in PHT can occur during the final weaning of iNO to < 5ppm with symptoms including higher PAP, systemic arterial desaturation and cardiovascular instability.
 - iNO therapy may need to be reinstated if the rebound PHT persists.
 - Iloprost (Ventavis): nebulized treatment, half-life 20-30 minutes, administer 6-9 times/day.
 - Tyvaso (treprostinil) inhalation solution, half-life 4-6 hours, administer 4 times/day
 - **Oral**
 - Sildenafil, Tadalafil (PDE5 inhibitor)
 - Hemodynamic effect of pulmonary vasodilation begins in 15 minutes and last several hours.
 - Pretreatment with enteral sildenafil one hour prior to discontinuing iNO has been shown to effectively prevent rebound PHTN in children.
 - Sildenafil is contraindicated in patients using nitrates.
 - Selective endothelin receptor blocker
 - Bosentan (Tracleer)
 - Ambrisentan
 - Macitentan
 - Oral Prostinoids: Treprostinil
 - **Intravenous/subcutaneous**
 - Flolan (Epoprostenol) (IV, half-life 3-6 minutes)

- Caution systemic hypotension
 - Treprostinil (Remodulin) subcutaneous (half-life 3-4 hours, IV or SC (Steinbis, 2008))
 - Caution systemic hypotension
 - Primacor (IV, inotropic & vasodilator effects)
 - Isuprel
- Combination therapy, evidence based treatment algorithm (Galie, et al., 2013)

Special considerations

- Pregnancy – contraindicated in patients with Eisenmenger syndrome, CHD and PHT
 - Progesterone only birth control therapies may be considered. Hormone therapies are avoided due to increased thrombosis risk .
- Single ventricle physiology
 - Fontan, Glenn procedures require low PVR for optimal post-operative cardiac output & survival
- Even mild elevations in PVR may result in severely depressed pulmonary blood flow, impaired left heart filling and poor cardiac output .
- Cyanotic heart disease
 - Eisenmenger physiology
 - Patients with palliative aortopulmonary shunts-BT shunt, central shunt (Waterston/Potts)
 - Unrepaired or palliated CHD
- Extensive patient education recommendations/guidelines for Eisenmenger syndrome patients are available.

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