

Pulmonary Hypertension in the Adult with Congenital Heart Disease

What the ICU Bedside Nurse Needs to Know

Jo Ann Nieves, MSN, RN, CPN, ARNP, PNP-BC
Nurse Practitioner, Cardiology
Miami Children's Hospital, Miami, Florida

Annette Haynes, MS, RN, CNS, CCRN
Cardiology Clinical Nurse Specialist
Stanford Hospital and Clinics, Palo Alto, California

Introduction

- The normal pulmonary vascular bed is a low pressure, low resistance circuit.
- Pulmonary hypertension (**PHT**) is defined as a 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) and an increased pulmonary vascular resistance (PVR) index (≥ 3 Wood units x meter squared)
- PHT has multiple potential causes including idiopathic PHT, lung diseases or hypoxia, chronic pulmonary artery (PA) vessel thromboemboli, drugs, toxins and multiple systemic or metabolic disorders. Causes may include acute respiratory distress syndrome, acute LV dysfunction, or following cardiac or thoracic surgery.
- Congenital and acquired heart disease can contribute to the development of PHT.
 - o PHT can result from multiple cardiac shunting conditions including atrial and ventricular septal defects, atrioventricular septal defects, truncus arteriosus, tetralogy of Fallot and other forms of complex congenital heart disease (CHD).
 - o **Unrepaired lesions that may present with PHT in the adult** with congenital heart disease:
 - Increased pulmonary blood flow (PBF) pressures (such as large ventricular septal defect or large ductus arteriosus)
 - Increased PBF pressures (unrepaired adult atrial septal defect)
 - Increased pulmonary venous pressures (pulmonary vein stenosis, mitral stenosis)
 - Systemic ventricular dysfunction, severe
 - Patients with residual PHT despite surgical repair of the congenital defect
 - Patients with palliative aortopulmonary shunts- Blalock Taussig shunt, central shunt (Waterston/Potts)
- 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 producing an imbalance in the production of pulmonary vasodilators and constrictors resulting in thickening of the pulmonary endothelium and narrowing of the vessels. Left untreated, vascular

- remodeling takes place contributing to further increases in pulmonary vascular resistance (PVR) and the eventual development of a pulmonary vasculature that is “fixed” unresponsive to vasodilators. The result will be right ventricular (RV) volume and pressure overload, which can progress to RV failure, hemodynamic deterioration and death.
- 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 increases in PVR or PAP can cause critical alterations or failure of the Fontan or Glenn circulations, decreased left ventricular filling, which 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.
 - Eisenmenger syndrome –
 - o Development of PHT resulting in a bidirectional shunt or predominantly right to left intracardiac shunt, hypoxemia and cyanosis which is *unresponsive* to oxygen administration.
 - o Progressive right ventricular failure and premature death will occur.
 - o 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

- In critical presentation, PHT care will focus on elimination of stimuli which further cause pulmonary vasoconstriction, along with treatments which promote pulmonary vasodilation (including oxygen administration) and improve ventricular function.
- Patients require anticipatory care to prevent severe exacerbations of PHT
- Promote care interventions which increase pulmonary vasodilation
- Avoid care interventions which result in additional pulmonary vasoconstriction

• **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
<i>Agitation / Pain</i>	<i>Sedation / anesthesia</i>
Excessive <i>hematocrit</i>	Normal to low hematocrit
Hyperinflation	Normal functional residual capacity
Atelectasis, hypoventilation	<i>Nitric Oxide</i>

Adapted from Wernovsky, published in Nieves, 2010

- Situations exacerbating PHT episodes
 - Cardiac surgery - despite what may be an adequate repair. 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 infection
 - SUCTIONING – endotracheal, particularly in children
- In PHT patients, acute elevations in PVR can lead to a “crisis” acute right sided heart failure, with decrease in cardiac output, systemic hypotension, acidemia (metabolic) and right-sided heart ischemia. This “*crisis*” can progress towards cardiovascular collapse and death.
- Operative or anesthetic interventions for 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.
- Goals of 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.

Clinical Assessment

- Frequent, ongoing 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
 - Temp: fever can be manifestation of infectious process or low-cardiac output and leads to increased energy expenditure
 - Heart rate: slow, fast
 - Murmur: prominent 2nd heart sound; holosystolic blowing murmur of tricuspid regurgitation, and murmur related to CHD
 - Right ventricular heave may be present.
 - Blood pressure: hypertension or late hypotension due to PHT “crisis”
 - CVP: reflection of volume status & RV function. Goal in care includes finding the optimal RA/CVP which provides the best cardiac output.
 - 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 .
 - Respiratory rate and effort
 - Oxygen saturation: must compare to patient’s baseline
 - A patent foramen ovale 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
- Rhythm- sinus, tachycardia, arrhythmia (chronic vs acute/new onset), ectopy (type, frequency), atrioventricular block (degree, stable or progressive)
- 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 (systolic/diastolic/continuous depends on congenital cardiac defect and tricuspid regurgitation)
 - lung sounds- coarse breath sounds associated with pulmonary edema, wheeze
- 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 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

Treatment

- Treatment in PHT patient with RV failure is directed at:
 - reducing PVR
 - improving cardiac output/RV function
 - correcting systemic arterial hypotension
 - avoiding tachyarrhythmias
- Anticipatory care
- Minimizing *exacerbations* in PAP elevations.
- Early identification 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 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</i> Decreased

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 as they can contribute to severe decrease in cardiac output
 - 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
 - Pulmonary vasodilators-assess effect on cardiac output (CO)
 - Optimize sedation, pain control
- Optimizing subpulmonary ventricular function
 - Inotropic IV: 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
- 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 is a key component in PHT by reducing PA pressure and improving cardiac output in any patient with PHT, regardless of the cause.
 - 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 is only 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.
 - Bosentan (Tracleer) selective endothelin receptor blocker
 - Ambrisentan selective endothelin receptor blocker
 - Sitaxsentan (Thelin) selective endothelin receptor blocker
- **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)
- Combination therapy, evidence based treatment algorithm published by R. Barst, 2009.

Associated Complications PHT

- Arrhythmias-sinus rhythm optimal
 - Arrhythmias can further impair cardiac output
- Renal dysfunction- secondary to impaired systemic perfusion
- Pulmonary dysfunction
 - May require mechanical ventilation support
- Thromboembolic event- anti-coagulation

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

- Use of Intrauterine coil impregnated with progestogen has proven efficacy and safety in this population.
- 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.

Copy of this document with complete references:

http://www.pcics.org/pdf/PulmonaryHypertension-with_citations.pdf

References:

Atz AM, Wessel DL: Sildenafil ameliorates effects of inhaled nitric oxide withdrawal, *Anesthesiology* 91(1):307-310, 1999.

Atz AM, Adataia I, Wessel DL: Rebound pulmonary hypertension after inhalation of nitric oxide, *Ann Thorac Surg* 62:1759-1764, 1996.

Barst R: *JACC* 2009

Carvalho, 1997: # 58 in Zamanian article

Chin: *JACC*, 2008

Diller GP, Gatzoulis MA : Pulmonary vascular disease in adults with congenital heart disease, *Circulation* 114:1039-1050, 2007.

Galie: *Circulation*, 2006

Kerbaul: 2004: # 55 in Zamanian

Knight D: Nitric Oxide. *Newborn Drug Services*, 2001, available at <http://www.akhealth.co.nz/newborn/DrugProtocols/NitricOxidePharmacology.htm>. Accessed December, 2008.

Landzberg MJ. Congenital heart disease associated pulmonary arterial hypertension, *Clinics in Chest Medicine* 28(1):1-13, 2007.

- McLaughlin V, Benza RL, Rubin LJ, et al: Addition of inhaled Treprostinil to oral therapy for pulmonary arterial hypertension, *Journal of the American College of Cardiology* 55:1915-22, 2010.
- Miller OI, Celermajer DS, Deanfield JE, Macrae DJ: Very-low-dose inhaled nitric oxide: A selective pulmonary vasodilator after operations for congenital heart disease, *J Thorac Cardiovasc Surg*, 108:487-94, 1994.
- Miro AM, Pinsky MR: # 48 in Zamanian article
- Moloney, 2003: # 116 in Zamanian
- Poongundran N, Theilen U, Warwick W, et al: Sildenafil prevents rebound pulmonary hypertension after withdrawal of nitric oxide in children, *American Journal of Respiratory and Critical Care Medicine* 174:1042-1047, 2006.
- Rabinovitch M: Pathophysiology of pulmonary hypertension. In Allen HD, Driscoll DJ, Feltes TF, Shaddy RE, editors: *Moss & Adams heart disease in infants, children, and adolescents including the fetus and young adult*, ed. 7, Philadelphia, 2008, Lippincott, Williams & Wilkins pp 1322-1354
- Roberts JD, Lang P, Bigatello LM, et al: Inhaled nitric oxide in congenital heart disease, *Circulation* 87:447-453, 1993.
- Roberts, 2003: # 115 in Zamanian
- Seckel: *Critical Care Nurse* 30(2): 45-52, 2010.
- Simonneau, G, Robbins, IM, Beghetti, M, et al: Updated Clinical Classification of Pulmonary Hypertension, *JACC* 54:s43-54, 2009.
- Steinbis S: Assessing pulmonary arterial hypertension, *The Clinical Advisor* Nov: 57-67, 2008.
- Uebing A., Steer PJ, Yentis SM, & Gatzoulis, MA: Pregnancy and congenital heart disease, *BMJ* 332:401-406, 2006.
- Warnes CA, Williams RG, Bashore TM, et al: ACC/AHA 2008 Guidelines for the Management of Adults with Congenital Heart Disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (writing committee to develop guidelines on the management of adults with congenital heart disease). *Circ* 118:e714-833, 2008.
- Wernovsky G, Chang AC, Wessel DL, Ravishankar C: Cardiac intensive care. In Allen HD, Driscoll DJ, Feltes TF, Shaddy RE, editors: *Moss & Adams heart disease in infants,*

children, and adolescents including the fetus and young adult, ed. 7, Philadelphia, 2008, Lippincott, Williams & Wilkins pp 448-480

Zamanian RT, Haddad F, Doyle RL, Weinacker AB: Management strategies for patients with pulmonary hypertension in the intensive care unit, *Crit Care Med* 35:2037- 2050, 2007.

9/2010