ASSESSMENT OF PULMONARY VASCULAR RESISTANCE (PVR) IN THE CATH LAB

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I THE PHYSIOLOGICAL PRINCIPLE AND FORMULA

- **Core Concept:** Pulmonary Vascular Resistance (PVR) represents the resistance the right ventricle must overcome to pump blood through the pulmonary vascular bed. In the catheterization laboratory, it is calculated using the hydraulic analog of Ohm's Law (Resistance = Pressure Gradient / Flow).
- **The Standard Formula: PVR = (Mean Pulmonary Artery Pressure [mPAP] - Mean Pulmonary Capillary Wedge Pressure [PCWP]) / Cardiac Output (CO)**.
- **Units of Measurement:** The standard clinical unit is the **Wood Unit (WU)** (mmHg·min/L). To convert Wood Units into absolute metric resistance (**dynes·sec·cm-5**), multiply Wood Units by **80**.
- **Normal and Diagnostic Values:** A normal resting PVR is **less than or equal to 2.0 Wood Units**. In the 2022 ESC/ERS Pulmonary Hypertension Guidelines, pre-capillary pulmonary hypertension is defined on Right Heart Catheterization (RHC) by **mPAP greater than 20 mmHg**, **PAWP (PCWP) less than or equal to 15 mmHg**, and **PVR greater than 2.0 Wood Units**.

II MANDATORY CATHETERIZATION MEASUREMENTS

- **Catheter System:** Accurate assessment requires meticulous acquisition of three distinct variables using a fluid-filled, multi-lumen balloon-tipped pulmonary artery catheter (**Swan-Ganz catheter**), zeroed precisely at the **mid-thoracic line (level of the left atrium)** in the supine patient.
- **Mean Pulmonary Artery Pressure (mPAP):** Measured directly with the catheter tip positioned in the main pulmonary artery.
- **Pulmonary Capillary Wedge Pressure (PCWP / PAWP):** Acts as a surrogate for Left Atrial Pressure and Left Ventricular End-Diastolic Pressure. It is mandatory that PCWP is measured precisely at **end-expiration** (without breath-holding or Valsalva) to eliminate the artifactual swings of intrathoracic pressure during the respiratory cycle.
- **Cardiac Output (Pulmonary Blood Flow — Qp):** The denominator of the equation; inaccurate measurement of flow is the single most common source of erroneous PVR calculation in the catheterization laboratory.

III METHODS OF MEASURING CARDIAC OUTPUT (THE DENOMINATOR)

- **Thermodilution Method:**
  - **Technique:** Injecting a known volume (typically 10 mL) of iced or room-temperature isotonic saline into the proximal right atrial port and integrating the temperature change over time via a distal thermistor in the pulmonary artery.
  - **Limitations and Contraindications:** While reliable in structurally normal hearts, thermodilution is **inaccurate and should not be used** in the presence of **intracardiac shunts**, **severe Tricuspid or Pulmonary Regurgitation**, or very low cardiac output states.
  - **The Direct/Indirect Fick Principle (The Gold Standard in Shunts and Valvular Disease):**
  - **Formula: Pulmonary Blood Flow (Qp in L/min) = Oxygen Consumption (VO2 in mL/min) / [(Pulmonary Venous O2 Content - Pulmonary Arterial O2 Content) x 10]**.
  - **Clinical Mandate:** The Fick method is **mandatory** for calculating Qp and PVR in all patients with **Congenital Heart Disease (intracardiac or extracardiac shunts)** or severe right-sided valvular regurgitation. Direct measurement of VO2 is preferred over assumed tables, and if 100 percent oxygen is inhaled during vasoreactivity testing, **dissolved plasma oxygen (0.003 x PaO2)** must be added to hemoglobin-bound oxygen content to prevent severe underestimation of PVR.

Method / Parameter	Formula / Acquisition Rule	Primary Advantage	Major Cath Lab Pitfall / Contraindication
PVR Formula	**(mPAP - PCWP or LAP) / Qp**	Separates pre-capillary resistance from left heart pressure	Must use **Indexed PVR (PVRi = PVR x BSA)** in children and small adults
Fick Method (Qp)	**VO2 / (CPVO2 - CPAO2)**	**Gold standard** in intracardiac shunts and severe TR	Must include **dissolved O2 (0.003 x PO2)** if testing on 100% FiO2
Thermodilution CO	Cold saline bolus in RA -> PA thermistor	Fast, reproducible in Idiopathic PAH (Group 1) without shunts	**Inaccurate** in intracardiac shunts, severe TR/PR, or very low CO
PCWP Measurement	Balloon occlusion in distal branch PA	Surrogate for Left Atrial Pressure	Must measure at **end-expiration**; "over-wedging" falsely elevates PCWP and underestimates PVR

IV PVR ASSESSMENT IN CONGENITAL HEART DISEASE (SHUNT OPERABILITY)

- **Modified Shunt Formula:** In patients with systemic-to-pulmonary shunts (ASD, VSD, PDA), pulmonary blood flow (**Qp**) differs from systemic blood flow (**Qs**); therefore, **PVR must be calculated using Qp** (never Qs) in the denominator: **PVR = (mPAP - Mean Left Atrial Pressure [or PCWP]) / Qp**.
- **Adult vs. Pediatric Operability Cut-offs (ESC 2020 ACHD / AHA):**
  - **ESC 2020 Adult Congenital (ACHD) Guidelines (Absolute PVR in Wood Units):** Shunt closure is **Class I recommended when PVR is less than 3 WU** (with a significant left-to-right shunt causing ventricular volume overload); **Class IIa when PVR is 3 to less than 5 WU** (with Qp:Qs >1.5); and **contraindicated (Class III) in irreversible PAH / Eisenmenger physiology when PVR remains >=5 WU** (unless reversible on targeted PAH therapy in ASD ["Treat-and-Repair", Class IIb]).
  - **Pediatric / Indexed PVR Criteria (PVRi in Wood Units·m2): PVRi less than 4 WU·m2** (with Rp/Rs <0.3) indicates safe operability; **PVRi 4 to 8 WU·m2** represents the borderline "grey zone" requiring further evaluation; and **PVRi greater than 8 WU·m2** generally indicates inoperable pulmonary vascular obstructive disease.

V ACUTE VASOREACTIVITY TESTING (AVT) IN THE CATH LAB

- **Guideline Indications in Group 1 PAH (ESC/ERS 2022 Class I):** In **Pulmonary Arterial Hypertension**, acute vasoreactivity testing is indicated **strictly in Idiopathic PAH (IPAH), Heritable PAH (HPAH), and Drug/Toxin-Associated PAH** solely to identify the ~10 percent of "acute responders" who can be safely treated with **high-dose Calcium Channel Blockers (CCBs)**. (AVT is not indicated to select CCBs in CTD-PAH, HIV-PAH, portopulmonary PH, or Group 2–5 PH.)
- **Recommended Short-Acting Vasodilator Agents (Class I):**
  - **Inhaled Nitric Oxide (iNO): 10 to 20 ppm for 5 to 10 minutes** (the **gold standard** agent due to selective pulmonary vasodilation and zero systemic hypotension).
  - **Inhaled Iloprost:** 5 to 20 mcg nebulized.
  - **Intravenous Epoprostenol** (2 to 12 ng/kg/min incremental titration) or **Intravenous Adenosine** (50 to 350 mcg/kg/min).
  - **Strict Contraindication (Class III):** Oral or intravenous **Calcium Channel Blockers (Verapamil, Diltiazem, Nifedipine)** or Sodium Nitroprusside **must NEVER be used for acute vasoreactivity testing** in the cath lab because they cause prolonged, potentially fatal systemic hypotension and RV ischemia.
  - **Positive Response Criteria in Group 1 PAH (The Sitbon Criteria — ESC/ERS Class I):** A positive vasoreactive response requires meeting **all three** criteria simultaneously:
  - **Reduction in Mean PAP by >= 10 mmHg** from baseline.
  - **Absolute final Mean PAP reaching <= 40 mmHg**.
  - **Cardiac Output that is increased or unchanged**.

KEY REFERENCES

- **Humbert M, Kovacs G, Hoeper MM, et al.:** 2022 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension, *European Heart Journal*, 2022.
- **Sitbon O, Humbert M, Jaïs X, et al.:** Long-term response to calcium channel blockers in idiopathic pulmonary arterial hypertension, *Circulation*, 2005.
- **Baumgartner H, De Backer J, Babu-Narayan SV, et al.:** 2020 ESC Guidelines for the management of adult congenital heart disease, *European Heart Journal*, 2020.