11 Hemodynamic Assessment: Right Heart Catheterization, Pulmonary Hypertension, Left-to-Right Shunt, and Constriction

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Hemodynamic assessment is a critical function of cardiac catheterization labs. Though significant advances in imaging modalities have replaced many of the functions of hemodynamic assessment, the catheterization laboratory still remains important for accurate measurements and the confirmation of diagnoses, especially in patients with suboptimal or equivocal imaging results

Indications

- Evaluate and perform hemodynamic assessment of valvular heart disease
- Evaluate and confirm the diagnosis of pulmonary hypertension
- Evaluate left-to-right shunt
- Differentiate constrictive from restrictive physiology
- Evaluate complex congenital heart disease (outside the scope of this text)

Contraindications

- Vegetation, tumor or thrombus in the right heart, mechanical prosthesis in the tricuspid or pulmonary position, hemodynamic or electrical instability [1]

Equipment

- 7–8 Fr sheath access kit
- Multi-lumen pulmonary artery (PA) catheter (alternatively, wedge catheter with 5–6 Fr sheath)

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Access 7–8 Fr femoral, internal jugular vein; 5–7 Fr antecubital (medial preferred)

Fluoroscopic Views Straight anterior-posterior (AP)

Steps for Standard Right Heart Catheterization

- Insert the PA catheter into the sheath (May use a leading J-tipped wire 0.035″, 0.018″ Platinum Plus or Swan wire, or 0.014″ support wire (Grand Slam or Iron Man) if using antecubital approach if needed). Advance the PA catheter to its 20 cm marker and inflate the balloon.
- Float the PA catheter into the right atrium (RA). Flush the system and zero the pressure transducer. Record the RA pressure. Advance the catheter into the right ventricle (RV). After recording the pressure, turn the catheter clockwise, transmitting torque by small back-forth motion of the catheter. When the tip of the catheter faces up in the right ventricular outflow tract (RVOT), advance the catheter (by pushing) into the pulmonary artery. Deep inspiration can assist in floating the catheter into the pulmonary artery. If difficulty is encountered, the catheter can be directed toward the lateral wall of the RA and looped to advance it into the RVOT and PA. If difficulty in floating the catheter persists, a Swan or 0.018″ Platinum Plus wire can be used to guide the catheter into the PA. The balloon should be deflated to allow for easy tracking of the catheter along the support wire. An appropriate pulmonary capillary wedge pressure (PCWP) tracing should be recorded with appropriate transition to PA waveform when the balloon is deflated. If the PCWP is hybridized, attempt advancing the catheter to wedge position with the balloon partially inflated or pull back by a different wedge position. Ideally, all pressure measurements are made at end-expiration (except in ventilated patients).
  - Note, for antecubital approach, it is easiest to allow the leading wire to guide the catheter directly into the PA and measure pressures on catheter pullback.
- For routine, right heart catheterization, measure the PA oxygen saturation. For Fick estimation of cardiac output (CO), arterial oxygen saturation can be assumed from pulse oximetry or measured directly if arterial access is present. Calculate the cardiac output and index by the Fick method (oxygen consumption is assumed, but can be measured directly).
- If using a PA catheter, connect the cable for thermodilution measurement of cardiac output and firmly inject 10 cc of saline in the proximal port (repeat two to three times). Thermodilution method may be omitted if severe tricuspid/pulmonic regurgitation is present.
- If severe pulmonary hypertension is present, and unexplained by pulmonary venous hypertension (normal PCWP), consider vasoreactivity testing (see below).
- If PA saturation is >75 % on repeated measurement and is not otherwise well explained (high-output state), an oxygen saturation run should be performed for detection and quantification of left-to-right shunt (see below).

Steps for Evaluation of Pulmonary Hypertension

- Perform standard right heart catheterization as described above. Calculate the transpulmonary gradient (TPG) and pulmonary vascular resistance (PVR). If there is doubt regarding the accuracy of the wedge pressure, a simultaneous left ventricular end-diastolic pressure should be measured via left heart catheterization.

$$\text{Transpulmonary gradient}\left(\text{TPG}\right) = \text{Mean PAP} - \text{PCWP}$$
$$\text{PVR}\left(\text{Woods}\right) = \text{TPG}\left(\text{mmHg}\right) / \text{CO}\left(\text{L} / \text{min}\right)$$

- If pulmonary arterial hypertension is present, defined by mean PA pressure >25 mmHg and a PVR >3 Wood units, and PCWP (and/or LVEDP) <15 mmHg, then acute vasodilator testing should be performed [2].
- For vasoreactivity testing, we administer inhaled nitric oxide at a dose of 40 parts per million (ppm) for 5 min, with continuous hemodynamic monitoring [3, 4]. Responders (or reactivity) to vasodilator testing (for purposes of initiating calcium channel blocker therapy) are defined as demonstrating a decrease in mean PAP by 10 mmHg to a mean PAP less than 40 mmHg without a decrease in cardiac output [2].

Steps for Evaluation of Left-to-Right Shunt

- Perform standard right heart catheterization as described above. Oxygen saturations can be measured on advancement or pullback of the catheter. When left-to-right shunt is not clinically suspected, a screening PA oxygen saturation should be measured; if the value is >75 % and unexplained by high cardiac output state and/or AV fistula, a complete saturation run should be performed.
- Oxygen saturations should be obtained from the pulmonary artery, right ventricle, right atrium, and superior vena cava. A difference between two chambers of approximately 5–7 % [5] is considered significant.
- Calculation of shunt fraction:
  - Use the difference in oxygen saturation to estimate ratio of flow across pulmonic (Q_p) and systemic circulatory (Q_s) beds:

$$Q_p / Q_s = \frac{\text{Arterial} - \text{Mixed venous}}{\text{Pulmonary venous} - \text{Pulmonary artery}}$$

  - With a few exceptions, arterial saturation can be used as a surrogate for the pulmonary venous saturation.
  - Mixed venous saturation is calculated as (3 SVC saturations + 1 IVC saturation)/4 otherwise it is assumed to be equivalent to the saturation from the chamber proximal to the suspected defect (saturation before "step up") and the IVC saturation can generally be excluded due to variability in measurement related to streaming and relative contribution to the average mixed venous saturation.
  - *Exceptions* to use of SVC saturation for mixed venous saturation measurement:
    - Anomalous pulmonary venous return above the SVC/RA junction.

  - Arteriovenous fistula or malformation above the SVC/RA junction.
  - In general these pitfalls can be overcome by measurement of venous saturation proximal to (above the level of) the shunts, if possible.
- Shunt calculation is not reliable in patent ductus arteriosus due to the distal site of shunting.

Complications While complications are generally rare (<1 %), the most common complications are access related (hematoma, pneumothorax). Additional adverse events may include usually transient arrhythmia due to catheter stimulation, vagal-induced hypotension, or reactions to vasoreactivity testing [6]. Vasoreactivity testing should be generally avoided in patients with significant, decompensated left heart disease or venoocclusive disease due to risk of pulmonary edema [2].

Post-procedural Care manual compression for hemostasis and routine post-procedural monitoring of vital signs

Steps for Evaluation of Constriction Versus Restriction

- Perform standard right heart catheterization as described above.
- Perform standard left heart catheterization, ideally with a pigtail catheter in the left ventricle.
- After zeroing both transducers and documenting simultaneous PCWP/LVEDP, deflate the PA catheter balloon and withdraw it slowly, until it falls into the right ventricle. The balloon can be reinflated in the RV to reduce ectopy.
- Slow the sweep speed and equalize the scales for measurement of simultaneous LV and RV pressures.
- If RA pressure was <15 mmHg, administer 1 litre of normal saline (fluid challenge).
- Hemodynamic tracings of LV/RV pressures typically demonstrate a "dip and plateau" or "square root sign" and, in constriction, usually with equalization of diastolic pressures.
- Hemodynamic criteria suggestive of constriction are included in Table 11.1:

Table 11.1 Hemodynamic criteria suggestive of constriction

	Constriction	Restriction
LVEDP–RVEDP (mmHg)	≤5	>5
PASP (mmHg)	≤55	>55
RVEDP/RVSP	>1/3	<1/3
Inspiratory fall in RAP (mmHg)	<5	>5
Inspiratory decrease in PCWP>LVDP	Present	Absent
Systolic area index	>1.1	<1.1

- In *constriction*, during inspiration, there is an *increase in the area of the RV* pressure curve (compared with expiration), and due to interventricular dependence, there is a simultaneous *decrease in the area of the LV* pressure curve.

$$\text{The systolic area index} = \frac{[\text{RV area} / \text{LV area}]_{\text{inspiration}}}{[\text{RV area} / \text{LV area}]_{\text{expiration}}}$$

  – Systolic area index >1.1 is highly suggestive of constriction [7].

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