Hemodynamics in the Cath lab and ICU

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Respected cardiologist and co-inventor of the Swan-Ganz catheter. He was born on Jan 1, 1922, in Sligo, Ireland; he died on Feb 7, 2005, after a heart attack in Los Angeles, CA, USA, aged 82 years.
The thermistor measures core body temperature. When connected to a cardiac output monitor, it measures temperature changes related to cardiac output.

The proximal lumen, usually blue, typically opens into the right atrium. In addition to measuring right atrial pressure, it delivers the bolus injection that's used to measure cardiac output and functions as a fluid infusion route.

The distal lumen, usually yellow, opens into the pulmonary artery. When attached to a transducer, it allows you to measure PAWP.

The balloon inflation valve serves as the access point for inflating the balloon at the distal tip of the catheter for PAWP measurement.

The inflated balloon wedges in a branch of the pulmonary artery during PAWP measurement.
Before you start

- Is a right heart catheterization planned?
- What kind of catheter is requested? Will it stay in?
- Which access site is planned?
  - Femoral? Internal Jugular? Brachial?
- How many transducers are requested?
- Flush all of the ports and connect yellow (distal port) to transducer. Use 3-way stopcocks
- Zero all of the transducers.
- Level all of the transducers to the phlebostatic level
**Phlebostatic Axis**

*Figure 3: The phlebostatic axis, marked on the patient’s chest, is the precise anatomical point of origin of the hemodynamic pressures being measured.*
Damping

- Normal
- Overdamped
- Underdamped
Optimal Damping Example

Squaring off as transducer reads pressure in pressurized flush bag

Only one block between bounces

Rapid decrease with release of flush device

2nd bounce < 1/3 height of 1st bounce

Small overshoot of baseline

Undershoot of baseline
<table>
<thead>
<tr>
<th>Pressure</th>
<th>Right atrium</th>
<th>Right ventricle</th>
<th>Pulmonary artery</th>
<th>Pulmonary capillary wedge</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mm Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 mm Hg</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>10 mm Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0 mm Hg</td>
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</tbody>
</table>

Flow-directed catheter
Mean RA ≈ RVedp
PA Systolic Pressure ≈ RV Systolic
PAedp and PAOP \approx LVedp
Aortic Systolic Pressure ≈ LV Systolic Pressure
Effects of Respiration on Waveforms

Spontaneous Ventilation

Inspiration

Exhalation

Mechanical Ventilation

Inspiration

Exhalation

ALWAYS MEASURE VALUES AT END-EXPIRATION!
Proper Swan Position
Distal PAC Position
Coiled PAC
Possible Complications

- Insertion
  - Arterial puncture (2-12%)
  - Pneumothorax (2%)
  - Air Embolism
  - Ventricular ectopy (> 30 PVCs in 3%)
  - Heart block (RBBB in 5%)
  - Catheter kinking/knotting
Possible Complications

- Use and maintenance
  - Pulmonary infarction
  - Pulmonary artery perforation/rupture
  - Mural thrombi (up to 30%)
  - Sterile valve vegetations
  - Endocarditis (<2%)

- Misinterpretation of hemodynamic data
Sources of error in measurement

- Improper leveling or zeroing of catheters
  - Movement of patient
- Positive pressure breathing
- Incomplete PA occlusion
- Large V waves
- Resonance artifact (underdamping)
West’s Zones of the Lung

- Only in Zone 3 do we obtain a continuous column of blood to the left atrium.
- Ideally place catheter below level of left atrium (only 60% success rate).
- Wide swings with respiration when non-Zone 3 conditions present.
When you inflate the balloon on the PA catheter, you observe the following waveform. The patient is spontaneously breathing. Is this a PAOP or is it a PA?
Answer - This a PAOP with large v waves. (Note the peak of the v wave occurs after the T wave.) The mean of the a wave at end-expiration varies between 38 and 48 mmHg.
Large \( v \) Waves in PAOP Waveform

- normally \( v \) wave is about the same height as the \( a \) wave
- Waveform may be mistaken for PA. Differentiate using ECG:
  - \( v \) wave of PAOP occurs well after the T wave
  - PA systolic peak occurs before the T wave

![Waveform Diagram]
Cardiac Output

- Cardiac output by Thermodilution
  - Cold or room temp fluid is injected into the CVP port of the catheter. The temperature of the fluid is measured by the thermistor on the distal port of the catheter.
  - Cardiac output is inversely proportional to the mean concentration of the indicator.

Figure 17-62A Thermodilution curves produced on a strip chart recorder. (A) Smooth recording is accurate.
Cardiac Output Curve Evaluation

Note 3 curves are similar in value and appearance.
Delete Curves That are Notched or Irregular
Cardiac Output: Technical Problems

- Variations in respiration:
  - Use average of 3 measures

- Blood clot over thermistor tip: inaccurate temp

- Cardiac Shunts:
  - R->L reduced peak, rapid washout, CO overestimated
  - L->R dilution of injectate, reduced peak, CO overestimated

- TR: attenuated peak and prolonged washout of signal, CO underestimated

- Computation constants:
  - Varies for each PAC, check package insert + manually enter
Cardiac Output:

The Fick Equation

Rate of indicator out = rate in + rate added

\[ Q \times C_{\text{out}} = Q \times C_{\text{in}} + V \]

\[ Q = \frac{V}{(C_{\text{out}} - C_{\text{in}})} \]

When \( O_2 \) is used as indicator:

\[ Q = \frac{V_{O_2}}{C_A O_2 - C_V O_2} \]

Direct Fick: \( V_{O_2} \) measurement
Indirect Fick: \( V_{O_2} \) estimate (3.5 ml/kg)

Murali, Medscape CME: Confirmation of PAH
Cardiac Output
Thermodilution vs Fick

Difference from Fick's method (%)

Low output  Normal output  Mild to moderate TR  Severe TR
Limitations of Fick

- VO2 is often estimated by body weight (indirect method) rather than by spirometry (direct methods).
- Large errors possible with small differences in saturations, hemoglobin.
- Patients should be on room air.
- Samples must be processed quickly/accurately.
Typical Cath lab hemodynamics: 
Left and Right heart Cath

- Measurements of right heart pressures and hemodynamics
- Measurement of LVEDP = ? CHF
- Measurement of LV/PCWP gradient = ?MS
- Measurement of LV/Ao gradient = ?AS
- Measurement of LV/RV response to inspiration = ?pericardial constriction
Most common technique for Mitral Gradients
PCW and LV

‘a’ wave delayed
‘v’ wave on LV down slope
BAMC Case #3117: Patient: 61 yo male
Dx: 3V CAD
filter: 50 Hz/ sample 250 Hz

Most Accurate Measurements of LV-AO gradient assessment:
2 pressure transducers close to the valve

Pre Contrast
Single Catheter pullback technique is not accurate enough for AS
Information Obtained from the PA Catheter

- Directly measured
  - CVP
  - PA pressure
  - PAOP/wedge pressure
  - Cardiac output
  - SvO₂

- Calculated from directly measured data
  - Stroke volume/index
  - Cardiac index
  - Systemic vascular resistance
  - Pulmonary vascular resistance
  - Oxygen delivery
Core Hemodynamic Variables

- Variable
  - Stroke volume/index
  - Cardiac output/index
  - CVP/RA
  - PAOP
  - SvO₂

- Assesses
  - pump performance
  - blood flow
  - filling pressures
  - filling pressures
  - tissue oxygenation
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SvO(_2)</td>
<td>0.60 - 0.75</td>
</tr>
<tr>
<td>Stroke volume</td>
<td>50-100 ml/beat</td>
</tr>
<tr>
<td>Stroke index</td>
<td>25-45 ml/beat/M(^2)</td>
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<tr>
<td>Cardiac output</td>
<td>4-8 L/min</td>
</tr>
<tr>
<td>Cardiac index</td>
<td>2.5-4.0 L/min/M(^2)</td>
</tr>
<tr>
<td>CVP</td>
<td>2-6 mm Hg</td>
</tr>
<tr>
<td>PAP</td>
<td>25/10 mm Hg</td>
</tr>
<tr>
<td>PAOP</td>
<td>8-12 mm Hg</td>
</tr>
</tbody>
</table>
Normal Hemodynamic Values

SVR  900-1300 dynes $sec/cm^5$

PVR  40-150 dynes $sec/cm^5$

MAP  70-110 mm Hg
What are we doing?

- Assessing adequacy of Circulation, or cause for inadequacy.

- Cardiac Output = HR x SV

- SV is a function of:
  - Preload (LVEDV)
  - Afterload (SVR)
  - Contractility/Inotropy
Problems Estimating LV Preload
- **Fick Equation**
  - $\text{VO}_2 = \text{CO} \times (\text{CaO}_2 - \text{CvO}_2)$
  - $\text{CvO}_2 \sim \text{SvO}_2$ b/c most O$_2$ in blood bound to Hg

- If O$_2$ sat, VO$_2$ + Hg remain constant, SvO$_2$ is indirect indicator of CO

- Use oximetric Swan, or send blood gas from PA

- Normal SvO$_2$ $\sim$ 65%

- $\downarrow$ SvO$_2$ [≤ 60%]
  - $\downarrow$ Hg- bleeding, shock
  - $\uparrow$ VO$_2$: fever, agitation, agitation,
  - $\downarrow$ SaO$_2$: hypoxia, resp distress
  - $\downarrow$ CO: MI, CHF, hypovolemia
# Etiology & Hemodynamic Changes in Shock

<table>
<thead>
<tr>
<th>Etiology of shock</th>
<th>example</th>
<th>CVP/PAOP</th>
<th>CO</th>
<th>SVR</th>
<th>SvO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>preload</td>
<td>hypovolemic</td>
<td>low</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>contractility</td>
<td>cardiogenic</td>
<td>high</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>afterload</td>
<td>distributive</td>
<td>low or high</td>
<td>high</td>
<td>low</td>
<td>low or high</td>
</tr>
</tbody>
</table>
Hemodynamic Therapeutic Interventions

- Fluids: low → high
  - Preload
- Vasopressors: low → high
  - Afterload
- Inotropic agents: low → high
  - Contractility
- high → Diuretics
- high → Venodilators
- Arterial dilators
- Calcium blockers
- ACE inhibitors
61 yo woman with hypotension (90/40) is admitted to the MICU and started on vasopressors. Her BP has improved to 110/70, pulse 90. She has an unexplained lactic acidosis of 5.0 mmol/L.

Swan Values:
- PAOP 18mmHg
- CVP 8mmHg
- C.I. 2.0 L/min/m2
- SvO2 0.45

How would you treat her?
Answer: Dobutamine

- Her Low SvO2 indicates severely impaired oxygen delivery
- Her low C.I. and high PAOP indicates that this is due to inadequate C.O.
- Her normal BP is due to a compensatory elevation in her SVR, which calculates to 1560!
- Echo eventually showed EF 20%.
- Stopped Dopamine, transfer to CCU.
A 20 yo man with a GSW to the abdomen has:

- HR 158, MAP 68 mm Hg,
- CVP 16 mm Hg, PCWP 20 mm Hg
- CO 10.2 L/min, SvO2 78%, SaO2 94%

What should he be given?

- A) Bolus IV fluids
- B) Dobutamine
- C) Supplemental Oxygen
- D) Antibiotics and vasopressors