Hemodynamics in the Cath lab and ICU

Arnold Seto, MD, MPA
UC-Irvine and Long Beach VA
H Jeremy C Swan

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

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

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>
<td></td>
<td></td>
</tr>
<tr>
<td>10 mm Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 mm Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mean RA ≈ RV_{edp}
PA Systolic Pressure ≈ RV Systolic
PAedp and PAOP \approx LVedp
Aortic Systolic Pressure $\approx$ 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
Cardiac Output

- Cardiac output by Thermодilution
  - 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

Direct Fick: VO2 measurement
Indirect Fick: VO2 estimate (3.5ml/kg)

Murali, Medscape CME: Confirmation of PAH
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 cardiac output, for calculation of valve areas
  
  \[
  \text{Valve area} = \frac{\text{Cardiac output}}{\sqrt{\text{Mean gradient}}}
  \]

- 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

ECG

40 mmHg

1 sec

LV

PCW

‘a’ wave delayed

‘v’ wave on LV down slope
Mitral Stenosis

Mean Mitral Gradient
15 mm Hg

Mean Mitral Gradient
6 mm Hg

LV
PAWP

LV
LA
Hemodynamics and Doppler Echo findings before MVBP

- MV DT = 628 msec
- P½ Time = 182 msec
- MV Area = 1.21 cm²
- 32.6 mmHg
Hemodynamic and Doppler Echo findings after MVBP

MV Peak E = 1.30 m/sec
Pk Grad = 6.8 mmHg

MV DT = 419 msec
P½ Time = 121 msec
MV Area = 1.82 cm²
Aortic Stenosis

The graph illustrates the changes in pressure over time in the aorta (Ao) and left ventricle (LV) in Aortic Stenosis.

- **Peak instantaneous pressure gradient**
- **Peak-to-peak gradient**
- **Mean gradient**

The graph shows the pressure curves over time, with the shaded area representing the mean gradient.
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
  - $\text{SvO}_2$

- 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
  - $SvO_2$

- Assesses
  - pump performance
  - blood flow
  - filling pressures
  - filling pressures
  - tissue oxygenation
Normal Hemodynamic Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SvO₂</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/M²</td>
</tr>
<tr>
<td>Cardiac output</td>
<td>4-8 L/min</td>
</tr>
<tr>
<td>Cardiac index</td>
<td>2.5-4.0 L/min/M²</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 $= HR \times SV$

- SV is a function of:
  - Preload (LVEDV, PCWP, CVP)
  - Afterload (SVR)
  - Contractility/Inotropy
Problems Estimating LV Preload

CVP (A) → PADP (B) → PAWP (C) → LAP (D) → LVEDP (E) → LV volume

- Diastolic RV P-V relation
- Tricuspid disease
- Pulmonary vascular resistance
- Heart rate
- Mitral valve disease
- Heart rate
- Alveolar pressure
- Pulmonary venous disease
- Diastolic LV P-V relation
LVEDP or pre-A LVDP?

In normal pts, difference between two is 1.6mmHg, so PADP, PCWP, LAP, and LVEDP and LVEDP are usually the same.

In pts with MI, CHF, LVEDP may be >> LAP due to contribution of atrial contraction.

LVEDP = ventricular preload.

Mean LAP and pre-A LVDP better measure of pulmonary congestion, correlates with PCWP.
- **Fick Equation**
  - $\text{VO}_2 = \text{CO} \cdot [\text{CaO}_2 - \text{CvO}_2]$
  - $\text{CvO}_2 \sim \text{SvO}_2$ b/c most $\text{O}_2$ in blood bound to Hg

- **If O2 sat, VO2 + Hg remain constant, SvO2 is indirect indicator of CO**

- **Use oximetric Swan, or send blood gas from PA**

- **Normal SvO2 $\sim 65\%$**

- **↓ SvO2 $[< 60\%]$**
  - ↓ Hg- bleeding, shock
  - ↑ VO2: fever, agitation,
  - ↓ SaO2 : hypoxia, resp distress
  - ↓ 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 → Preload: high → Diuretics, Venodilators
- Vasopressors: low → Afterload: high → Arterial dilators, Calcium blockers, ACE inhibitors
- Inotropic agents: low → Contractility
Quiz

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 12 mmHg
- C.I. 2.0 L/min/m2
- SvO2 0.45

How would you treat her?
- A) Bolus IV fluids
- B) Dobutamine
- C) Supplemental Oxygen
- D) Antibiotics and vasopressors
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.
Quiz

- 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
45 yo man with systemic hypoxemia, O2 sat 80%, referred for evaluation of right to left shunt. Normal PFTs, h/o cirrhosis.

Standard shunt run?

Sats obtained from all 4 pulmonary veins show O2 sat 80%.

Dx: Intrapulmonary shunts due to cirrhosis

Rx: Liver transplant.