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.

- 5841 Acute MI patients in SPRINT registry, 371 with PACs. No adjustment for patient factors. PAC more often placed in older patients.
“Heart catheterization may raise death risk for critically ill, study finds.”

“Extremely ill patients who undergo pulmonary artery catheterization have about a 25 percent greater chance of dying within six months of the procedure as similarly ill people who don't get it.”
Impact of the Pulmonary Artery Catheter in Critically Ill Patients
Meta-analysis of Randomized Clinical Trials

Figure 2. Odds Ratio (PAC vs No PAC) for Mortality of RCTs Evaluating the Safety and Efficacy of the PAC

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of Deaths/Total No. of Patients</th>
<th>Odds Ratio (95% CI)</th>
<th>Favors PAC</th>
<th>Favors No PAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schultz et al,15 1985</td>
<td>PAC 1/35, No PAC 10/35</td>
<td>0.11 (0.02-0.63)</td>
<td></td>
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</tr>
<tr>
<td>Shoemaker et al,16 1988</td>
<td>PAC 11/58, No PAC 7/30</td>
<td>0.76 (0.27-2.15)</td>
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<tr>
<td>Isaacson et al,17 1990</td>
<td>PAC 1/49, No PAC 0/53</td>
<td>NA</td>
<td></td>
<td></td>
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<tr>
<td>Berlauk et al,18 1991</td>
<td>PAC 1/66, No PAC 2/21</td>
<td>0.18 (0.02-1.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guyatt,19 1991</td>
<td>PAC 10/16, No PAC 9/17</td>
<td>1.10 (0.29-4.22)</td>
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<tr>
<td>Bender et al,20 1997</td>
<td>PAC 1/51, No PAC 1/53</td>
<td>1.04 (0.11-9.95)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valentine et al,21 1998</td>
<td>PAC 3/60, No PAC 1/60</td>
<td>2.38 (0.35-16.29)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bonazzi et al,22 2002</td>
<td>PAC 0/50, No PAC 0/50</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhodes et al,23 2002</td>
<td>PAC 46/95, No PAC 50/106</td>
<td>1.01 (0.58-1.76)</td>
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</tr>
<tr>
<td>Sandham et al,24 2003</td>
<td>PAC 163/997, No PAC 155/997</td>
<td>1.06 (0.83-1.35)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Richard et al,25 2003</td>
<td>PAC 199/338, No PAC 208/343</td>
<td>0.93 (0.68-1.26)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESCAPE,10 2005</td>
<td>PAC 45/215, No PAC 38/218</td>
<td>1.25 (0.78-2.02)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvey et al,14 2005 (PAC-Man)</td>
<td>PAC 346/506, No PAC 333/507</td>
<td>1.13 (0.87-1.47)</td>
<td></td>
<td></td>
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<tr>
<td>Combined</td>
<td></td>
<td>1.04 (0.90-1.20)</td>
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</tbody>
</table>

JAMA. 2005;294:1664-1670
Declining PAC use

A Rates Among All Medical Patients

PA Catheter Use per 1000 Admissions

Year
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
Flow-directed catheter

<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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<tr>
<td>10 mm Hg</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0 mm Hg</td>
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</tbody>
</table>
Mean RA $\approx$ 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
- Non-zone 3 conditions
- Positive pressure breathing
- Incomplete PA occlusion
- Large V waves
- Resonance artifact (underdamping)
- Effect of catheter across stenotic valve
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
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

Direct Fick: VO2 measurement
Indirect Fick: VO2 estimate (3.5ml/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 LV/PCWP gradient
- Measurement of LV/Ao gradient
- Measurement of LV/RV response to inspiration
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
  - tissue oxygenation
<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 x SV

- SV is a function of:
  - Preload (LVEDV)
  - Afterload (SVR)
  - Contractility/Inotropy
Problems Estimating LV Preload
Fick Equation

- \( VO_2 = CO \ [CaO_2 - CvO_2] \)
- \( CvO_2 \sim SvO_2 \) b/c most O2 in blood bound to Hg

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

Can be measured using oximetric Swan or CVP, or send blood gas from PA / CVP

Normal SvO2 \( \sim 65\% \) [60-75]
Mixed Venous Oximetry

- ↓ SvO2 [< 60%]
  - ↓ Hg- bleeding, shock
  - ↑ VO2: fever, agitation, thyrotoxic, shivering
  - ↓ SaO2: hypoxia, resp distress
  - ↓ CO: MI, CHF, hypovolemia
Mixed Venous Oximetry

- $\uparrow \text{SvO}_2 [> 75\%]$  
  - Wedged PAC: reflects LAP saturation
  - Low VO2: hypothermia, general anesthesia, NMB
  - Unable to extract O2: cyanide, Carbon monoxide
  - High CO: sepsis, cirrhosis, burns, L→R shunt AV fistulas
## 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
- Vasopressors: low
- Inotropic agents: low
- Preload: high
- Afterload: high
- Contractility: low

- Diuretics
- 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
Conclusions

- Pulmonary artery catheters generate patient and time specific hemodynamic information.

- There is no evidence from randomized controlled trials to support its routine use in sepsis, CHF, ARDS, or perioperatively.

- There is a small increase in risk of individual complications with its use, but no overall increase in mortality or morbidity in most studies.