HEMODYNAMIC MONITORING

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Definitions and Principles

- The measurement and interpretation of biological systems that describe performance of the cardiovascular system
- Monitoring is NOT therapy
- Clinicians must know how to interpret the data
- Very few randomized controlled trials
Oxygen Delivery is the Goal

**Oxygen Delivery**

\[
DO_2 (\text{mL O}_2/\text{min}) = \text{CO (L/min)} \times \text{CaO}_2 (\text{mL O}_2/\text{dL}) \times 10
\]

\[
\text{CO (L/min)} = \text{HR (beats/min)} \times \text{SV (L/beat)}
\]

\[
\text{CaO}_2 (\text{mL O}_2/\text{dL}) = [1.34 \times (\text{Hb})(\text{g/dL}) \times \text{SaO}_2] + [.003 \times \text{PaO}_2 \text{ mm Hg}]
\]

**Oxygen Consumption**

\[
\text{CVO}_2 (\text{mL O}_2/\text{dL}) = [1.34 \times (\text{Hb})(\text{g/dL}) \times \text{SVO}_2] + [.003 \times \text{PVO}_2 \text{ mm Hg}]
\]

\[
\dot{V}O_2 (\text{mL O}_2/\text{min}) = \text{CO} \times 3(\text{CaO}_2 - \text{CVO}_2) \times 10
\]
Determinants of Cardiac Performance

- **Preload**
  - Estimated by end-diastolic volume (pressure)
  - CVP for RVEDV, PAOP (wedge) for LVEDV

- **Afterload**
  - \( \text{SVR} = \frac{\text{MAP} - \text{CVP}}{\text{CO}} \times 80 \)

- **Contractility**
Methods of Hemodynamic Monitoring

- Arterial Blood Pressure
  - Non-invasive
  - Direct arterial pressure measurement
- Central Venous Pressure
- The Pulmonary Artery Catheter
- Cardiac Output Measurement
- Tissue Oxygenation
Non-invasive Blood Pressure Monitoring
Non-invasive Blood Pressure Measurement

- Manual or automated devices
- Method of measurement
  - Oscillometric (most common)
    - MAP most accurate, DP least accurate
  - Auscultatory (Korotkoff sounds)
    - MAP is calculated
  - Combination
Limitations of Non-invasive Blood Pressure Monitoring

- Cuff must be placed correctly and must be appropriately sized
- Auscultatory method is very inaccurate
  - Korotkoff sounds difficult to hear
  - Significant underestimation in low-flow (i.e. shock) states
- Oscillometric measurements also commonly inaccurate (> 5 mm Hg off directly recorded pressures)
Direct Arterial Blood Pressure Measurement
Indications for Arterial Catheterization

- Need for continuous blood pressure measurement
  - Hemodynamic instability
  - Vasopressor requirement
- Respiratory failure
  - Frequent arterial blood gas assessments
- Most common locations: radial, femoral, axillary, and dorsalis pedis
Complications of Arterial Catheterization

- Hemorrhage
- Hematoma
- Thrombosis
- Proximal or distal embolization
- Pseudoaneurysm
- Infection
Pseudoaneurysm

Fig. 1 – Photography of colour Doppler result showing right axillary artery pseudoaneurysm
Limitations of Arterial Catheterization

- Pressure does not accurately reflect flow when vascular impedance is abnormal
- Systolic pressure amplification
  - Mean pressure is more accurate
- Recording artifacts
  - Underdamping
  - Overdamping
Waveform Distortion
Central Venous Catheterization

- Central venous pressure
  - Right atrial (superior vena cava) pressure
  - Limited by respiratory variation and PEEP

- Central venous oxygen saturation
  - $\text{ScVO}_2$
  - Correlates with $\text{SMVO}_2$ assuming stable cardiac function
  - Goal-directed resuscitation in severe sepsis and septic shock (Rivers, et al)
Central Venous Pressure Waveform
The Pulmonary Artery Catheter

- HJ C Swan and sailboats
- Widespread use in critically ill patients
- Remains controversial
  - Lack of prospective, randomized trials
  - PAC data are only as good as the clinicians’ interpretation and application
- Measures CVP, PAP, PAOP, Cardiac Index and SVO$_2$
Pulmonary Artery Catheter
Indications for Pulmonary Artery Catheterization

- Identification of the type of shock
  - Cardiogenic (acute MI)
  - Hypovolemic (hemorrhagic)
  - Obstructive (PE, cardiac tamponade)
  - Distributive (septic)
- Many critically ill patients exhibit elements of more than 1 shock classification
- Monitoring the effectiveness of therapy
# Normal Hemodynamic Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>SVO2</td>
<td>60-75%</td>
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<tr>
<td>Stroke volume</td>
<td>50-100 mL</td>
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<tr>
<td>Stroke index</td>
<td>25-45 mL/M²</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/M²</td>
</tr>
<tr>
<td>MAP</td>
<td>60-100 mm Hg</td>
</tr>
<tr>
<td>CVP</td>
<td>2-6 mm Hg</td>
</tr>
<tr>
<td>PAP systolic</td>
<td>20-30 mm Hg</td>
</tr>
<tr>
<td>PAP diastolic</td>
<td>5-15 mm Hg</td>
</tr>
<tr>
<td>PAOP (wedge)</td>
<td>8-12 mm Hg</td>
</tr>
<tr>
<td>SVR</td>
<td>900-1300 dynes·sec·cm⁻⁵</td>
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</tbody>
</table>
Hemodynamic Profiles in Shock

<table>
<thead>
<tr>
<th>Class of Shock</th>
<th>CVP</th>
<th>PAOP</th>
<th>CO/ CI</th>
<th>SVR</th>
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</thead>
<tbody>
<tr>
<td>Cardiogenic</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Hypovolemic</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Hyperdynamic septic</td>
<td>↑</td>
<td>⇨</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>Hypodynamic septic</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>
Pulmonary Artery Catheter Placement
Complications of Pulmonary Artery Catheterization

- General central line complications
  - Pneumothorax
  - Arterial injury
  - Infection
  - Embolization
- Inability to place PAC into PA
- Arrhythmias (heart block)
- Pulmonary artery rupture
The Pulmonary Artery Catheter Controversy

- Accuracy of data affected by many conditions common in critically ill patients
- Lack of prospective randomized data supporting better outcomes with PAC
- Limited by the ability of the clinician to accurately interpret PAC data
Cardiac Output Measurement

- Multiple techniques
  - Thermodilution - most common
  - Transpulmonary
  - Pulse contour analysis
  - Esophageal Doppler

- Newer pulmonary artery catheters offer continuous cardiac output measurement
Thermodilution Method of Cardiac Output Measurement
Tissue Oxygenation

- Despite advances, our ability to monitor the microcirculation and tissue perfusion is limited
- Laboratory tests for metabolic acidosis are global and insensitive
- Newer technology on the horizon
  - Gastric tonometry
  - Sublingual capnometry
Conclusions

- Multiple different methods of hemodynamic monitoring

- Keys to success
  1) Know when to use which method
  2) Technical skills for device placement
  3) Know how to interpret the data

- Remember the limitations of the technology