Hemodynamic Monitoring for the Critically Ill Patient

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Disclosure Statement

• I have no conflicts of interest relevant to topics covered in this presentation.
Learning Objectives

• Review the rationale for hemodynamic monitoring critically ill patients.

• Compare different modalities for hemodynamic monitoring in ICU patients and the evidence for their use.

• Consider which modalities for hemodynamic monitoring we may use most in the future and how they will be used.
Shock Pathophysiology

• Impaired oxygen delivery and resultant end organ dysfunction.

• Organ failure progresses and death ensues.
Shock Pathophysiology: Oxygen Delivery

\[ \text{VO}_2 = \text{Cardiac Output} \times (C_{a\,O_2} - C_{v\,O_2}) \]

\[ = (\text{HR} \times \text{SV}) \times \left[ ((\text{SaO}_2 \times \text{Hb} \times 1.34) + 0.003(\text{PaO}_2)) - ((\text{SvO}_2 \times \text{Hb} \times 1.34) + 0.003(\text{PvO}_2)) \right] \]
Shock Pathophysiology: Mean Arterial Pressure

\[
MAP = (CO \times SVR) = ((HR \times SV) \times SVR)
\]
Therapeutic Interventions We Can Make

• Improve Cardiac Filling Pressures (Preload)
  » Fluid Boluses

• Increase SVR and therefore MAP
Therapeutic Interventions We Can Make

• Improve Cardiac Filling Pressures (Preload)
  » Fluid Boluses

• Increase SVR and therefore MAP
  » α receptor agonism
  » vasopressin
  » dopamine

• Increase Cardiac Output
  » Dobutamine β1 and β2 agonism
  » Milrinone
  » Intra-aortic balloon pump

• Improve the oxygen content of the blood
  » Improve SaO₂ via mechanical ventilation
  » Increase O₂ carrying capacity of blood (transfusions)
Shock Pathophysiology: Mean Arterial Pressure

- MAP ≥ 60mmHg is necessary to maintain end organ perfusion in most cases.

- Higher MAP may be necessary in select cases
  - Intracranial Hypertension – Hemorraghe, Cerebral Edema, Closed Head trauma, Large Strokes
  - Chronic HTN
What Do We Monitor, and Why?

• Variables we can directly influence to reverse aberrant physiology
  • MAP
  • HR
  • CVP

• Variables that we monitor to tell if our interventions are reversing aberrant physiology
  • Lactate
  • Urine output
  • Mixed venous oxygen saturation
What Do We Monitor, and Why?

• Cuff Blood Pressure
• Intra-arterial blood pressure
• Central Venous Pressure
• Pulmonary Artery Catheter
  • RV Pressure
  • PA Pressure
  • Pulmonary Capillary Wedge Pressure
  • CO/CI
• Cardiac Output
• Echocardiography / IVC Diameter
Monitoring: Cuff Blood Pressure

- Oscillatory Automated Blood Pressure Monitors

![Graph showing blood pressure measurement process]

- All oscillations will be recorded.
- The highest pulse wave is determined.
- An envelope will be recorded.
- Based on the highest point of the envelope SYS and DIA are calculated with the help of an algorithm.
Monitoring: Cuff Blood Pressure

Situations where potentially unreliable:

- Caridiac Arrythmias (especially rapid Afib)
- Increased SVR / Circulatory Shock
- Calcified Arteries
Monitoring: Cuff Blood Pressure

• Manual Cuff Pressures / Ausculatory Method
  – Inflate Cuff and listen for Korotkoff Sounds to determine systolic and diastolic pressures.

• Calculate MAP = (SPB + 2(DBP)) / 3
Monitoring: Intra Arterial Blood Pressure

• The gold standard for accurate assessment of blood pressure

• Provides continuous data

• Not essential, but probably should be considered any time vasopressor agents are used
Monitoring: Intra Arterial Blood Pressure
Monitoring: Central Venous Pressure
Monitoring: Central Venous Pressure

**a wave** = atrial contraction

**c wave** = ventricular contraction against closed tricuspid
descend = closed tricuspid valve being pulled toward ventricle by ventricular contraction

**v wave** = atrial filling

**y descent** = ventricular filling, tricuspid valve open
Monitoring: Central Venous Pressure

- Estimates cardiac filling pressures and helps us estimate whether hypotension might be fluid responsive or not.
Central Venous Pressure: Severe Sepsis and Septic Shock

Figure 2. Protocol for Early Goal-Directed Therapy.
CVP denotes central venous pressure, MAP mean arterial pressure, and Svo₂ central venous oxygen saturation.

Central Venous Pressure: Acute Respiratory Distress Syndrome (ARDS)

<table>
<thead>
<tr>
<th>Measured intravascular pressure (mm Hg)</th>
<th>MAP &lt; 60 mm Hg or a need for any vasopressor (except dopamine ≤ 5 µg/kg/min); consider correctable causes of shock first</th>
<th>MAP ≥ 60 mm Hg without vasopressors (except dopamine ≤ 5 µg/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVP</td>
<td>Liberal strategy</td>
<td>Conservative strategy</td>
</tr>
<tr>
<td></td>
<td>Range 1</td>
<td>Range 2</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Range 2</td>
<td>15–18</td>
<td>13–18</td>
</tr>
<tr>
<td>Range 3</td>
<td>10–14</td>
<td>8–12</td>
</tr>
<tr>
<td>Range 4</td>
<td>&lt;10</td>
<td>&lt;8</td>
</tr>
</tbody>
</table>

1. Vasopressor\(^F\) Fluid bolus\(^F\)
2. Fluid bolus\(^F\) Vasopressor\(^F\)
3. KVO IV Dobutamine\(^A\) Furosemide\(^B,1,2,4\)
4. KVO IV Dobutamine\(^A\)
5. Fluid bolus\(^C\)
6. Fluid bolus\(^C\)
7. KVO IV Furosemide\(^B,1,2,4\)
8. KVO IV Furosemide\(^B,1,2,4\)
9. Fluid bolus\(^C\)
10. Fluid bolus\(^C\)
11. KVO IV Dobutamine\(^A\) Furosemide\(^B,1,3,4\)
12. KVO IV Dobutamine\(^A\)
13. Fluid bolus\(^C\)
14. Fluid bolus\(^C\)
15. KVO IV Furosemide\(^B,1,3,4\)
16. KVO IV Furosemide\(^B,1,3,4\)
17. Liberal KVO IV
18. Conservative Furosemide\(^B,1,3,4\)
19. Liberal fluid bolus
20. Conservative KVO IV

NHLBI ARDS Clinical Trials Network. *NEJM* 2006. 354:2564
Monitoring: The Pulmonary Artery Catheter

- Cardiac Output
- Cardiac Index
- Systemic Vascular Resistance
- Pulmonary Vascular Resistance

Clinical use of the pulmonary artery catheter

<table>
<thead>
<tr>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differentiation among causes of shock</td>
</tr>
<tr>
<td>Cardiogenic</td>
</tr>
<tr>
<td>Hypovolemic</td>
</tr>
<tr>
<td>Distributive (sepsis)</td>
</tr>
<tr>
<td>Obstructive (massive pulmonary embolism)</td>
</tr>
<tr>
<td>Differentiation between mechanisms of pulmonary edema</td>
</tr>
<tr>
<td>Cardiogenic</td>
</tr>
<tr>
<td>Noncardiogenic</td>
</tr>
<tr>
<td>Evaluation of pulmonary hypertension</td>
</tr>
<tr>
<td>Diagnosis of pericardial tamponade</td>
</tr>
<tr>
<td>Diagnosis of left-to-right intracardiac shunt</td>
</tr>
<tr>
<td>Diagnosis of lymphangitic spread of tumor and fat embolism (case reports based on blood aspirated from wedge position)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Therapy</th>
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</thead>
<tbody>
<tr>
<td>Management of perioperative patient with unstable cardiac status</td>
</tr>
<tr>
<td>Management of complicated myocardial infarction</td>
</tr>
<tr>
<td>Management of patients following cardiac surgery</td>
</tr>
<tr>
<td>Management of severe preeclampsia</td>
</tr>
<tr>
<td>Guide to pharmacologic therapy</td>
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<tr>
<td>Vaspressors</td>
</tr>
<tr>
<td>Inotropes</td>
</tr>
<tr>
<td>Vasodilators (for patients with pulmonary hypertension)</td>
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<tr>
<td>Guide to nonpharmacologic therapy</td>
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<tr>
<td>Fluid management</td>
</tr>
<tr>
<td>Gastrointestinal bleed</td>
</tr>
<tr>
<td>Traumatic exsanguination</td>
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<tr>
<td>Burns</td>
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<tr>
<td>Renal failure</td>
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<tr>
<td>Sepsis</td>
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<tr>
<td>Heart failure</td>
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<tr>
<td>Decompensated cirrhosis</td>
</tr>
<tr>
<td>Ventilator management (assessment of best PEEP for O2 delivery)</td>
</tr>
</tbody>
</table>
Monitoring: The Pulmonary Artery Catheter

- Studies have shown no benefit with use of pulmonary artery catheters

- Different experienced providers come to different conclusions based on the same data from PAC’s

- Use is now very limited. Usually used to answer a very specific question.
Its All About Fluid Responsiveness!

• Trial and Error
  • Fluid Challenge
  • Passive Leg Raising Maneuvre

• New High Tech Evaluations
  • PiCCO
  • Pulse Pressure Variation
  • Bedside Ultrasound Evaluation of the IVC
The passive leg-raising test consists of measuring the hemodynamic effects of a leg elevation up to 45°. A simple way to perform the postural maneuver is to transfer the patient from the semi-recumbent posture to the passive leg-raising position by using the automatic motion of the bed.
Hemodynamic Monitoring: Pulse Pressure Variation

• Relies on the principal that stroke volume and therefore blood pressure will vary with alterations in preload induced by respiratory cycles on positive pressure ventilation.
Hemodynamic Monitoring:
Pulse Pressure Variation

- PiCCO and LiDCCO Both use arterial waveform tracings to derive cardiac output by using proprietary algorithms to convert pressure based signals into flow measurements.
- They also use thermodilution to estimate intrathoracic blood volume, extravascular lung volume, and cardiac output.
- They require an CVP and an arterial line.
### Hemodynamic Monitoring: PiCCO

**Figure 14 Decision tree for advanced hemodynamic management using PiCCO**

<table>
<thead>
<tr>
<th>CO* (l/min/m²)</th>
<th>&lt; 3.0</th>
<th>&gt; 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITBV* (ml/m²)</td>
<td>&lt; 850</td>
<td>&gt; 850</td>
</tr>
<tr>
<td>EVLW* (ml/kg)</td>
<td>&lt; 10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Therapy</td>
<td>V+</td>
<td>V+ (!)</td>
</tr>
<tr>
<td></td>
<td>Cat</td>
<td>Cat</td>
</tr>
<tr>
<td></td>
<td>V+</td>
<td>V+ (!)</td>
</tr>
<tr>
<td></td>
<td>OK</td>
<td>V-</td>
</tr>
<tr>
<td>Target:</td>
<td>temporary</td>
<td>temporary</td>
</tr>
<tr>
<td>ITBV*</td>
<td>850-1000</td>
<td>750-850</td>
</tr>
<tr>
<td>CFI</td>
<td>&gt; 4.5</td>
<td>&gt; 5.5</td>
</tr>
<tr>
<td>EVLW* (slowly responding!)</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
</tr>
</tbody>
</table>

V+ = volume loading (! = cautiously); V- = volume contraction; Cat = inotropic / vasoactive support instructions without guarantee

V+ = volume loading (! = cautiously); V- = Volume contraction; Cat = inotropic / vasoactive support
Hemodynamic Monitoring: Bedside Ultrasonography and Focused Echocardiography

• IVC diameter and variation with respiration has been used validated as predictive for fluid responsiveness patients breathing spontaneously and on mechanical ventilation.

• Hyperdynamic ventricles or severe ventricular dysfunction
Hemodynamic Monitoring: Bedside Ultrasonography and Focused Echocardiography

Figure 1 Individual values of inferior vena cava collapsibility (cIVC) (%) after infusion of 500 mL of HES. The best cutoff value is 40%.

From Muller, L. et al. *Critical Care*. 2012. 16:R188
How Do We Use These New Technologies?

• Extrapolation of what the data obtained means to our patient’s current pathophysiology

• We need algorithmic data that show how these data should be interpreted and intervened upon, and that those interventions improve outcomes.
Axioms of Effective Critical Care Delivery

1. Make your patients get evidence based care and therapies that we KNOW will improve outcome FIRST!

2. Don’t allow other data to push you to interventions that contradict evidence based therapies.

3. Use hemodynamic data to try to maintain normal physiologic parameters and reverse deteriorating organ function.
References

- Up to Date Online. Pulmonary artery catheterization.