Functional Hemodynamic Monitoring and Management

A practical Approach

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Early Optimization of Hemodynamics improves outcome

Kern JW and Shoemaker WC
Crit Care Med 30: 1686 – 1692, 2002
Metaanalysis of hemodynamic optimization in high risk patients

Early goal-directed therapy in the treatment of severe sepsis and septic shock
Goals of hemodynamic Management

1. Optimizing Stroke volume /Cardiac Output:
   - Measurement of SV/CO

2. Optimizing Preload:
   - Measurement of Preload
   - Assessing Fluid Responsiveness

3. Avoiding Fluid Overload
   - Assessing Pulmonary Edema
Preload Optimization as primary Step to optimize SV/CO

Preload

low

(too) high

CO ?

? Macrocirculatory Dysfunctions

? Microcirculatory Dysfunctions

? Organ Failure

CO ??

? (Macrocirculatory Dysfunctions)

? Formation of Edema

? Microcirculatory Dysfunctions

? Organ Failure
Ventricular Function Curve

Stroke volume

Preload
Stepwise Fluid Loading to optimize SV

Randomised controlled trial assessing the impact of a nurse delivered, flow monitored protocol for optimisation of circulatory status after cardiac surgery

Moira McKendry, Helen McGloin, Debbie Saberi, Libby Caudwell, Anthony R Brady and Mervyn Singer

BMJ 2004;329:258-
Stepwise Fluid Loading to optimize SV

Table 2: Management of patients in four hours after cardiac surgery. Values are means (standard deviations)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Control group (n=85)</th>
<th>Protocol group (n=99)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid requirement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colloid (ml)</td>
<td>1042 (620)</td>
<td>1667 (464)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Crystalloid (ml)</td>
<td>328 (99)</td>
<td>353 (95)</td>
<td>0.09</td>
</tr>
<tr>
<td>Change in measure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke volume (ml)</td>
<td>-10.2 (18.4)</td>
<td>1.5 (18.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cardiac output (l/min)</td>
<td>-0.46 (1.68)</td>
<td>0.45 (1.98)</td>
<td>0.001</td>
</tr>
<tr>
<td>Corrected flow volume (ms)</td>
<td>-0.325 (59.7)</td>
<td>-6.2 (67.5)</td>
<td>0.007</td>
</tr>
<tr>
<td>Peak velocity (cm/s)</td>
<td>-2.7 (16.6)</td>
<td>2.6 (14.4)</td>
<td>0.08</td>
</tr>
<tr>
<td>Arterial base excess (mmHg)</td>
<td>-0.73 (1.60)</td>
<td>-0.54 (2.19)</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Table 4: Number of patients with complications after cardiac surgery

<table>
<thead>
<tr>
<th>Postoperative complication</th>
<th>Protocol group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial fibrillation requiring treatment</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Cerebral vascular accident</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Chest infection or sternal wound infection</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Gastrointestinal bleed or perforated duodenal ulcer</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Acute renal failure</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Pleural effusion</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Infected leg wound</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Aortic regurgitation</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Death</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Any of above</td>
<td>17</td>
<td>26</td>
</tr>
</tbody>
</table>
CVP and PAOP do not allow quantitative Assessment of Preload

Kumar et al; Crit Care Med; 2005
Ventricular function curve

Stroke volume

Preload Volume
Volumetric preload monitoring

Transesophageal Echocardiography
LVEDA
**Volumetric Preload Monitoring**

Injection of Indicator (cv-line)

- ITBV: intrathoracic Blood Volume
- GEDV: global end-diastolic Volume

**EVLW:**

- RAEDV
- RVEDV
- PBV
- LAEDV
- LVEDV

**arterial Catheter (PiCCO)**
Volumetric Preload Monitoring

Michard F et al; Chest 125: 1900-1908; 2003
How to define “best” Preload?

stroke volume

preload volume

volume dependency

volume independency
**Fluid Responsiveness: CVP**

- $r^2 = 0.08$
- $p > 0.05$

Heart-Lung-Interactions during MV

⇒ $P_{\text{intrathoracic}} \uparrow$
⇒ venous
⇒ Return to RV/LV ↓
⇒ LV Preload ↓
⇒ LVSV ↓
Stroke Volume Variation by arterial Pulse Contour Analysis

Stroke Volume Variation (SVV)

\[ SVV = \frac{SV_{\text{max}} - SV_{\text{min}}}{SV_{\text{mean}}} \]
SVV
-Mechanism-

SVV

Preload (Volume)
Prediction of fluid responsiveness: SVV


Early hemodynamic Goals

- optimized SV
- optimized preload
- prevent pulm. edema

Organ Function
Avoiding Fluid Overload
Chest X-Ray vs. EVLW

Eisenberg PR et al., CritCare Med 5: 549-553, 1984
**EVLW in ARDS: The Mitchell-Study**

- **Probability of requiring mechanical ventilation**
  - EVLW (n=40) vs. WP (n=42)

- **Probability of still being in ICU**
  - EVLW (n=52) vs. WP (n=49)

**Transcardiopulmonary Thermodilution:**

**Extravascular Lung Water (EVLW)**

Injection of Indicator (cv-line) (PiCCO)

EVLW: extravascular Lung Water

Arterial Catheter (PiCCO)
Experimental Validation EVLW by Thermodilution

Kirov MY et al; J Crit Care 2004
Pulmonary-Artery versus Central Venous Catheter to Guide Treatment of Acute Lung Injury

The National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome (ARDS) Clinical Trials Network*
<table>
<thead>
<tr>
<th>Complication</th>
<th>PAC Group Sheath</th>
<th>PAC Group CVC</th>
<th>CVC Group Sheath</th>
<th>CVC Group CVC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical and mechanical complications</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficult placement</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Catheter malfunction</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Air embolism</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Arterial puncture</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td><strong>Arrhythmia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atrial</td>
<td>3</td>
<td>15</td>
<td>0</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Ventricular</td>
<td>4</td>
<td>15</td>
<td>0</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>Conduction defect</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td><strong>Bleeding and clotting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hemothorax</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Insertion-site bleeding</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Thromboembolism</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Local thrombosis</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td><strong>Infection</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Bloodstream*</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>23</td>
<td>59</td>
<td>18</td>
<td>100</td>
<td>6</td>
</tr>
</tbody>
</table>

*Bloodstream* indicates bloodstream infections.
'Preload-directed Therapy'

CO, GEDV, ITBV, EVLW

The Practical Approach
80 cardiac surgery patients (CABG)

- Study group: \( n = 40 \)
- Controls: \( n = 40 \) (matched pairs)
- Study period: start of surgery – 48 h post op
Treatment Algorithm CO / GEDV / EVLW

GEDVI > 640 ?
  yes → CI > 2.5 ?
    yes → MAP > 70 ?
      yes → GOOD!!
      no → GEDVI > 800 ?
        yes → give Volume until GEDVI > 800
        no → EVLWI > 10 ?
          yes → give Volume until GEDVI > 640
          no → no

GEDVI > 800 ?
  no → give catecholamines until CI > 2.5

MAP > 70 ?
  no → EVLWI > 10 ?
    yes → give catecholamines until MAP > 70
    no → no

EVLWI > 10 ?
  no → no
IV Volume on ICU

Colloids

Algorithm

Controls

Goepfert MS et al. (submitted)
Total norepinephrine on ICU

Norepinephrine

Controls

Algorithm

Goepfert MS et al. (submitted)
Total epinephrine on ICU

Epinephrine

Controls

Algorithm

Goepfert MS et al. (submitted)
Rationale hemodynamic management?

- avoid dehydration
- maintain preloading blood volume? determine it!
- prevent inadequate tissue perfusion? measure SV/CO!
- prevent fluid overload

Consider escalating update monitoring strategies and adequate early goal directed algorithms including the complete perioperative process oriented at functional hemodynamic monitoring (e.g. SV, SVV, PPV, GEDVI, EVLW)