Advance in PICU Monitoring

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Monitor is derived from the word “Monere” means “To Warn or Remind”

Monitoring means using oversight to detect threats early enough for effective intervention. Permit timely intervention to avoid potentially harmful consequences.
Ideal Monitoring System

- Safe, non-invasive, associated with no discomfort, responsive to real time change
- Data would be reliable, accurate, repeatable, continuously displayed, able to be stored and retrieved
- Least invasive monitoring that is appropriate for diagnosis, patient safety, assessment of treatment
Advance in PICU Monitoring

Intracranial

Intra-Thoracic Hemodynamic

Intra-Abdomen Abdominal Compartment Syndrome
Hemodynamic Monitoring

- Understanding Principles/Practice essential for management of critically ill child
- Knowledge pathophysiology and physical Principles of technology
  Limitations
  Potential errors
## Cardiac Output Clinical Monitoring Tools

<table>
<thead>
<tr>
<th>Mental status</th>
<th>Heart rate/rhythm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of hydration</td>
<td>Pulse characteristics</td>
</tr>
<tr>
<td>Peripheral edema</td>
<td>Urine output</td>
</tr>
<tr>
<td>Respiratory pattern</td>
<td>Hepatomegaly</td>
</tr>
<tr>
<td>Peripheral perfusion</td>
<td>Jugular venous pressure</td>
</tr>
<tr>
<td>Toe-to-core temperature gap</td>
<td>Pulmonary and cardiac auscultation</td>
</tr>
</tbody>
</table>
Important of Hemodynamic Monitoring

- To identify occult tissue hypo-perfusion.
- Blood pressure is the last variable to decrease.
- Tachycardia is sensitive but not specific.
- Urine output is useful but can be misleading.

Lactate is non-specific.
Functional Hemodynamic Monitoring

Existing applications

- Volume Responsiveness
- Vaso-Motor tone
- Cardiac contractility
- Cardio-Vascular reserve.
Hemodynamic Monitoring
The Role of Circulation

Deliver Oxygen and Nutrients to the Cells

Volume

DO₂

Oxygen content

CO

CaO₂

HR

SV

SpO₂

Hb

SVR

Preload

Contractility

Afterload

BP

Advance PICU monitoring
Cardiac output monitoring

- Invasive CO Monitoring
  PAC

- Mini-Invasive CO Monitoring
  PICCO, SCVO₂, TEE etc.

- Non-Invasive CO monitoring
  USCOM, NICOM, ECHO etc.
CO measurement

Technique

- Transpulmonary thermodilution (PAC)
- Pulse wave analysis
- Doppler technique
- Fick principle (partial CO$_2$ rebreathing)
- Electrical bioimpedance
Minimally invasive CO

- Pulse wave analysis
- PiCCO (Pulsion, Germany)
- LiDCO (LiDCO, UK)
- Flotrac/Vigileo (Edwards Life science)

- Doppler measurement technique
  TEE
  Esophageal Doppler flow probe
Non-Invasive CO Monitoring

- Fick method (Partial CO2 rebreathing)
- NICO
- TTEcocardioogram
- Ultra Sonic CO Monitor (USCOM)
Continuous arterial pressure monitor

- Arterial line
- Pressure bag
- Pressure transducer & automatic flushing system
- Saline filled non-compressible tubing
Pulse contour analysis

CO = SV x HR

Pulse pressure ∝ SV/aortic compliance

Less Invasive, real time and continuous monitor, relative CO estimation
A comparison of pressure recording analysis and Doppler echocardiography.


PICU
N= 48
Age 1 month – 18 y/o
Femoral/radial artery cath with MV
PRAM (Mostcare, Italy)
PediaSat Continuous ScvO$_2$ Oximetry Catheter

- Clinician requested, & guides therapy
- Multi-lumens for pressure monitoring, infusing & labs
- Sized for pediatrics
- Compatible with any Edwards oximetry monitor
- Soft catheter tip with fiber-optics

Continuous ScvO$_2$ monitoring

Flexible back-form with two suture loops
### Product Configurations

<table>
<thead>
<tr>
<th>Model</th>
<th>5cm</th>
<th>8cm</th>
<th>15cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5F Double Lumen</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5.5F Triple Lumen</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Compatible for use with existing Edwards oximetry monitors

![Image of product configurations]

![Image of Edwards oximetry monitor]
Reflection Spectrophotometry

[Diagram showing LED photo detector, transmission fiber, receiving fiber, and SVC]
Specific Monitor
Arterial/CVL with special catheter
Advance PICU monitoring
ScvO\textsubscript{2}

Oxygen Delivery
- Hemoglobin
- Cardiac output
  - Heart rate
  - Stroke volume
- Oxygenation / ventilation
  - Preload
  - Afterload
  - Contractility

Oxygen Consumption
- Metabolic demands
  - FiO\textsubscript{2}

Reinhart K et al Curr Opin Crit Care 2005;11:259
- Has been considered a surrogate for cardiac output/index in pediatrics

Tibby et al Arch Dis Child 2003
“Adequate” oxygenation can only be defined when tissue \(O_2\) supply matches tissue \(O_2\) demand

- Usually consumption (\(VO_2\)) independent of delivery (\(DO_2\))

\[
VO_2 = \text{CO} \times (\text{SaO}_2 - \text{SvO}_2) \times \text{Hgb} \times 1.34 \times 10 = 120-200 \text{ ml/min/m}^2
\]

\[
DO_2 = \text{CO} \times \text{SaO}_2 \times \text{Hgb} \times 1.34 \times 10 = 650 \pm 50 \text{ ml/min/m}^2
\]

- If \(VO_2\) increases or \(DO_2\) decreases, tissue oxygenation is maintained by increasing oxygen extraction

\[
O_2\text{ER} = \frac{VO_2}{DO_2} \times 100 = 25 \pm 2\%
\]

- If \(DO_2\) drops below a critical level, oxygen extraction becomes exhausted resulting in \(VO_2\) dependent on \(DO_2\) or oxygen debt

**Tissue hypoxia occurs!**

Note: Oxygen extraction increases well before lactate begins to accumulate
<table>
<thead>
<tr>
<th>$\text{ScvO}_2$ / $\text{SvO}_2$</th>
<th>Physiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-75%</td>
<td>Normal extraction (non-cyanotic cardiac)</td>
</tr>
<tr>
<td>&lt; 70% and &gt; 50%</td>
<td>Compensatory extraction ($\uparrow$ demand or $\downarrow$ supply)</td>
</tr>
<tr>
<td>&lt; 50% and &gt; 30%</td>
<td>Limits of extraction (beginning of lactic acidosis)</td>
</tr>
<tr>
<td>&lt; 30% and &gt; 25%</td>
<td>Severe lactic acidosis</td>
</tr>
<tr>
<td>&lt; 25%</td>
<td>Cellular death</td>
</tr>
</tbody>
</table>

### Medications

<table>
<thead>
<tr>
<th>Medication</th>
<th>Increase % VO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norepinephrine (0.10-0.31 µ/kg/min)</td>
<td>10-21%</td>
</tr>
<tr>
<td>Dopamine (5 µ/kg/min)</td>
<td>6%</td>
</tr>
<tr>
<td>Dopamine (10 µ/kg/min)</td>
<td>15%</td>
</tr>
<tr>
<td>Dobutamine</td>
<td>19%</td>
</tr>
<tr>
<td>Epinephrine (0.10 µ/kg/min)</td>
<td>23-29%</td>
</tr>
</tbody>
</table>

### Medications / Intervention

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Decrease % VO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothermia (each 1°C)</td>
<td>10%</td>
</tr>
<tr>
<td>MSO$_4$ (IVP)</td>
<td>9-21%</td>
</tr>
<tr>
<td>MSO$_4$ (IVCD)</td>
<td>21%</td>
</tr>
<tr>
<td>Anesthesia</td>
<td>25-50%</td>
</tr>
<tr>
<td>Assist/control ventilation</td>
<td>30%</td>
</tr>
<tr>
<td>Neuromuscular blockade</td>
<td>50-100% (if shivering)</td>
</tr>
<tr>
<td>Factors</td>
<td>% Increase in VO$_2$</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Non-sedated head injury</td>
<td>138%</td>
</tr>
<tr>
<td>Burns</td>
<td>100%</td>
</tr>
<tr>
<td>Sepsis</td>
<td>50 - 100%</td>
</tr>
<tr>
<td>Shivering</td>
<td>50 - 100%</td>
</tr>
<tr>
<td>MODS</td>
<td>20 - 80%</td>
</tr>
<tr>
<td>Work of breathing</td>
<td>40%</td>
</tr>
<tr>
<td>Weighing patient</td>
<td>36%</td>
</tr>
<tr>
<td>Changing position</td>
<td>31%</td>
</tr>
<tr>
<td>Suctioning</td>
<td>27%</td>
</tr>
<tr>
<td>CXR</td>
<td>25%</td>
</tr>
<tr>
<td>Bath</td>
<td>23%</td>
</tr>
<tr>
<td>Fever, Dressing change</td>
<td>10%</td>
</tr>
</tbody>
</table>
Benefits of Continuous vs. Intermittent

Real-time, no waiting for analysis results

Cost savings
• Financial
• Resources of staff
• Prevention

Decrease risk for infection

Early warning
• Identification of $DO_2/VO_2$ imbalance
• Traditional hemodynamic monitoring unreliable

Decrease risk for transfusions
Conclusion:

Goal-directed therapy using the endpoint of a $\text{ScvO}_2 \geq 70\%$ has a significant and additive impact on the outcome of children and adolescents with septic shock.
Clinical practice parameters for hemodynamic support of pediatric and neonatal septic shock: 2007 update from the American College of Critical Care Medicine*

**Conclusion:** The 2007 update continues to emphasize early use of age-specific therapies to attain time-sensitive goals, specifically recommending 1) first hour fluid resuscitation and inotrope therapy directed to goals of threshold heart rates, normal blood pressure, and capillary refill ≤2 secs, and 2) subsequent intensive care unit hemodynamic support directed to goals of central venous oxygen saturation >70% and cardiac index 3.3–6.0 L/min/m². (Crit Care Med 2009; 37:666–688)
Conclusions:
We report the first case of a newly modified central venous catheter for children and demonstrate its utility in a patient with impaired oxygen delivery when traditional markers remain stable. This catheter enabled the rapid diagnosis of cardiac compromise due to pericardial effusion, leading to early treatment.
Pulse wave analysis/CO
PiCCO-Tecnology

- CVL
- Pulsiocath (Pulsion Medical, Germany) thermodilution catheter with lumen for arterial pressure measurement femoral a (3-7 fr)
Recognize decreased mental status and perfusion. Begin high flow O₂. Establish IV/IO access.

**Initial resuscitation:** Push boluses of 20 cc/kg isotonic saline or colloid up to & over 60 cc/kg until perfusion improves or unless rales or hepatomegaly develop. Correct hypoglycemia & hypocalcemia. Begin antibiotics.

**shock not reversed?**

**Fluid refractory shock:** Begin inotrope IV/IO. Use atropine/ketamine IV/IO/IM to obtain central access & airway if needed. Reverse cold shock by titrating central dopamine or, if resistant, titrate central epinephrine Reverse warm shock by titrating central norepinephrine.

**shock not reversed?**

**Catecholamine resistant shock:** Begin hydrocortisone if at risk for absolute adrenal insufficiency.

Monitor CVP in PICU, attain normal MAP-CVP & ScvO₂ > 70%

**Cold shock with normal blood pressure:**
1. Titrate fluid & epinephrine, ScvO₂ > 70%, Hgb > 10 g/dL
2. If ScvO₂ still < 70%
Add vasodilator with volume loading (nitrovasodilators, milrinone, imrinone, & others)
Consider levosimendan

**Cold shock with low blood pressure:**
1. Titrate fluid & epinephrine, ScvO₂ > 70%, Hgb > 10 g/dL
2. If still hypotensive consider norepinephrine
3. If ScvO₂ still < 70% consider dobutamine, milrinone, enoximone or levosimendan

**Warm shock with low blood pressure:**
1. Titrate fluid & norepinephrine, ScvO₂ > 70%
2. If still hypotensive consider vasopressin, terlipressin or angiotensin
3. If ScvO₂ still < 70% consider low dose epinephrine

**Persistent catecholamine resistant shock:** Rule out and correct pericardial effusion, pneumothorax, & intra-abdominal pressure > 12 mm/Hg. Consider pulmonary artery, PICCO, or FATD catheter, &/or doppler ultrasound to guide fluid, inotrope, vasopressor, vasodilator and hormonal therapies.

Goal C.I. > 3.3 & < 6.0 L/min/m²

**shock not reversed?**

**Refractory shock:** ECMO
CO: Partial rebreathing

Fick Principle

CO = Pulmonary blood flow

Low MV can cause high shunt fraction and a false high CO.

Advance PICU monitoring