The PiCCO system

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Disclosure

The speaker cooperates with the following companies

BMeye
Drager-Siemens
Pulsion

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The PiCCO

A multi-parametric approach to advanced hemodynamic monitoring
Clinical examination, vital signs, urine output, Hb, lactate...

- Preload & Fluid responsiveness
- EVLW
- dP/dT, CFI, GEF, PVPI
- ScvO₂
- Cardiac Output

Clinical examination, vital signs, urine output, Hb, lactate...

- Preload & Fluid responsiveness
- EVLW
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- ScvO₂
- Cardiac Output
A man with fever and shortness of breath

ScvO₂ 72%
CVP 9 mmHg
Lactate 48
PaO₂/FiO₂ 75 (PEEP 10)

• CO 3.8
• ITBVI 950 (normal)
• EVLWI 15 (high)
• SVR 1100

Real-time CCO by the pulse contour method

\[ P(t) = \text{cal} \cdot \text{HR} \cdot \left( \int_{\text{Systole}} \left( \frac{P(t)}{\text{SVR}} + C(p) \cdot \frac{dP}{dt} \right) dt \right) \]

Arterial compliance and resistance are updated beat-to-beat according to a proprietary algorithm that depends particularly on the arterial pressure and on dP/dt.
measurements recorded when SVR changed > 15%

Whole set of CI pairs

After a 1-hr calibration-free period, recalibration may be encouraged since it provides helpful information drawn from other thermodilution-derived variables.

Clinical examination, vital signs, urine output, Hb, lactate...

Preload & Fluid responsiveness

EVLW

dP/dT, CFI, GEF, PVPI

Cardiac Output

ScvO₂
Clinical examination, vital signs, urine output, Hb, lactate...

**Preload & Fluid responsiveness**

- EVLW
- Cardiac Output
- dP/dT, CFI, GEF, PVPI
- ScvO₂

Intra-thoracic blood volume (ITBV)

\[ ITBV = CO \cdot mtt \]
**Global End-Diastolic Volume as an Indicator of Cardiac Preload in Patients With Septic Shock**


![Graph showing pre-infusion and GEDVi changes for responders and non-responders.]

% of fluid-responders

**ITBV and its changes correlate to CI and its changes significantly better than the CVP**

Volume assessment in patients with necrotizing. A comparison of intrathoracic blood volume index (ITBI), central venous pressure, and hematocrit, and their correlation to cardiac index and extravascular lung water index

Wolfgang Huber; Andreas Uengauer; Wolfgang Reindl; Michael Franzen; Christian Schmidt; Stefan von Delfs; Fatihlen Gebler; Florian Eickel; Ralph Fristch; Jens Sivcejek; Benedikt Hermelinet; Roland M. Schmidt

*Crit Care Med* 2008; 36: 2348

**Performance of Bedside Transpulmonary Thermodilution Monitoring for Goal-Directed Hemodynamic Management After**

Tatsushi Mutoh, MD, DVM, PhD; Ken Kazumara, MD; Tatsuya Ishikawa, MD; Shunsuke Terasaka, MD

*Stroke* published online May 21, 2009

![Graph showing ITBV changes and % of fluid-responders.]

% of fluid-responders
Intravascular volume depletion in a 24-hour porcine model of intra-abdominal hypertension

Should we monitor preload and fluid responsiveness in shock?
Functional hemodynamic parameters (SPV, PPV, SVV) are the most sensitive parameters for the assessment of fluid responsiveness in mechanically ventilated patients.

<table>
<thead>
<tr>
<th>SPV</th>
<th>PPV</th>
<th>SVV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Clinical examination, vital signs, urine output, Hb, lactate...

- Preload & Fluid responsiveness
  - EVLW
  - Cardiac Output
    - dP/dT, CFI, GEF, PVPI
    - ScvO₂
High EVLW content is associated with increased mortality (65-80% when EVLW>20 ml/kg)

Sakka S et al
Chest 2002; 1232:2080-6

EVLWI and Mortality
(Highest measurement)
N=373

Beale R 2001

Impact of extravascular lung water index on outcomes of severe sepsis patients in a medical intensive care unit
FT Chung et al, respiratory Medicine 2008
EVLW was markedly elevated (13.5 ml/kg) in patients with early ARDS, was significantly higher in non-survivors and correlated with Vd/Vt.

Accuracy of transpulmonary thermodilution versus gravimetric measurement of extravascular lung water

Rita Katzenelson; Azriel Perel; Heilim Berkernstadt; Sergel Pekelman; Samuel Kogan; Leonid Sternik; Eran Segal

(Crit Care Med 2004; 32:1550–1554)

- 15 dogs; EVLW measured by PiCCO and, following sacrifice, by gravimetrics.
- Control (n=5)
- Non-cardiogenic pulmonary edema (oleic acid) (n=5)
- Cardiogenic pulmonary edema (lt. atrial balloon) (n=5)
A 63 yrs old patient with pulmonary edema after TURT 24 hours later

Severe respiratory failure in a 33 yrs old patient following ruptured hematoma of the liver and multiple transfusions EVLW is only 5 ml/kg
A patient with head injury, severe ARDS and septic shock

BP 70/40 mmHg
HR 155 bpm
CVP 5 cmH$_2$O
Pa$_O_2$/Fi$_O_2$ 80 (PEEP 16)

Noradrenaline + aggressive diuresis!

A classic therapeutic (heart vs. lungs) conflict

An old patient with chronic heart failure, sepsis, severe respiratory failure and hemodynamic instability.

CO 1.8 l/min LOW
ITBVi 600 ml/m$^2$ LOW
EVLWi 15 ml/kg HIGH
SVV 25-30% HIGH
A 63 years old male patient; developed fulminant pulmonary edema 4 hours into a re-total hip replacement. Hypoxemia (SaO2<80%), hemodynamic instability and ST changes. In the PACU – hypotensive, tachycardic, on vasopressors and inotropes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal range</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>1.9 l/m²</td>
<td>3.5 - 5.0 Low CO</td>
</tr>
<tr>
<td>ITBVI</td>
<td>779 ml/m²</td>
<td>850 -1000 Low preload</td>
</tr>
<tr>
<td>SVV</td>
<td>22 %</td>
<td>&lt;10 High fluid responsiveness!!</td>
</tr>
<tr>
<td>EVLW</td>
<td>23 ml/kg</td>
<td>3 - 7 Severe pulmonary edema</td>
</tr>
</tbody>
</table>
**Decision tree for hemodynamic / volumetric monitoring**

<table>
<thead>
<tr>
<th>CI (l/min/m²)</th>
<th>1.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITBVI (ml/m²)</td>
<td>779</td>
</tr>
<tr>
<td>SVV %</td>
<td>22</td>
</tr>
<tr>
<td>EVLW (ml/kg)</td>
<td>23</td>
</tr>
</tbody>
</table>

**Starting parameters**
- CI > 3.0
- GEDI or ITBI > 700 ml/m²

**Starting hemodynamic:**
- CO (L)
- GEDV (L)
- EVLW (H)

**Fluid loading decision:**
- Start fluid loading!
- Stop fluid loading!

**Adjustments:**
- V+ volume loading (!! = cautiously)
- V- volume contraction
- Cat = catecholamine / cardiovascular agents

**Notes:**
- SVV only applicable in ventilated patients without cardiac arrhythmia
- *not available in USA*
This ‘flash’ permeability of uncertain etiology (TRALI?) was associated with severe hypovolemia and improved spontaneously even though fluids were liberally administered.

<table>
<thead>
<tr>
<th></th>
<th>PACU</th>
<th>Fluid loading</th>
<th>Postop Day 1</th>
<th>Postop Day 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI (l/min)</td>
<td>1.9</td>
<td>3.75</td>
<td>2.89</td>
<td>3.47</td>
</tr>
<tr>
<td>ITBVI (ml/m²)</td>
<td>779</td>
<td>1444 !!!!</td>
<td>972</td>
<td>1093</td>
</tr>
<tr>
<td>SVV %</td>
<td>22</td>
<td>15</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>EVLW (ml/kg)</td>
<td>23</td>
<td>15</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Clinical examination, vital signs, urine output, Hb, lactate...

- Preload & Fluid responsiveness
- EVLW
- dP/dT, CFI, GEF, PVPI
- Cardiac Output
- ScvO₂
34 yr female; Very severe respiratory failure; Hemodynamic collapse; on noradrenaline.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP</td>
<td>113 / 67 mmHg</td>
</tr>
<tr>
<td>HR</td>
<td>91 bpm</td>
</tr>
<tr>
<td>Urine</td>
<td>Good</td>
</tr>
<tr>
<td>SaO₂</td>
<td>86% !!!</td>
</tr>
<tr>
<td>ScvO₂</td>
<td>80% !!!</td>
</tr>
<tr>
<td>CI</td>
<td>2.7 l/min/m²</td>
</tr>
<tr>
<td>ITBVi</td>
<td>578 ml/m²</td>
</tr>
<tr>
<td>EVLWi</td>
<td>20 ml/kg</td>
</tr>
<tr>
<td>ICG PDR</td>
<td>6.7% (18-25%)</td>
</tr>
<tr>
<td>ITBVi</td>
<td>1099</td>
</tr>
<tr>
<td>SVAV</td>
<td>1.128</td>
</tr>
<tr>
<td>EVAV</td>
<td>1.018</td>
</tr>
<tr>
<td>PiCCO₁</td>
<td>2.218</td>
</tr>
<tr>
<td>PiCCO₂</td>
<td>2.192</td>
</tr>
<tr>
<td>PiCCO₃</td>
<td>2.100</td>
</tr>
<tr>
<td>PiCCO₄</td>
<td>2.034</td>
</tr>
<tr>
<td>PiCCO₅</td>
<td>3.862</td>
</tr>
<tr>
<td>PDR</td>
<td>2.344</td>
</tr>
</tbody>
</table>

Have we achieved initial resuscitation goals in this patient?
The patient population included 206 patients, which were evaluated by 166 residents and 146 specialists (total of 315 questionnaires).

Participants were asked to predict advanced hemodynamic parameters and decide on a therapeutic plan prior to PiCCO insertion.

The main reasons for using the PiCCO monitoring system included:

- Unclear fluid status (136)
- Suspected sepsis / septic shock (89)
- Respiratory failure (59)
- Cardiogenic shock (24)
- Renal failure (32)
- Other (21)
### The accuracy of predicted cardiopulmonary parameters

<table>
<thead>
<tr>
<th></th>
<th>CO (n=315)</th>
<th>SVR (n=312)</th>
<th>GEDVi (n=314)</th>
<th>EVLWi (n=304)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underestimation &gt;20%</td>
<td>170 (54%)</td>
<td>46 (14.7%)</td>
<td>97 (30.9%)</td>
<td>83 (27.3%)</td>
</tr>
<tr>
<td>Within ± 20%</td>
<td>110 (34.9%)</td>
<td>107 (34.3%)</td>
<td>154 (49%)</td>
<td>124 (40.8%)</td>
</tr>
<tr>
<td>Overestimation &gt;20%</td>
<td>35 (11.1%)</td>
<td>159 (51%)</td>
<td>63 (20.1%)</td>
<td>97 (31.9%)</td>
</tr>
</tbody>
</table>

The PiCClin Study

### The PiCClin Study

II: Change of therapeutic plan following advanced cardiopulmonary monitoring in critically ill patients

In the absence of further hemodynamic information, what would be your therapeutic decision?

<table>
<thead>
<tr>
<th>Fluid loading</th>
<th>Red blood cells</th>
<th>Inotropic agent</th>
<th>Vaso-constrictor</th>
<th>Diuretic</th>
<th>Dialysis/filtration</th>
<th>Other</th>
</tr>
</thead>
</table>
The PiCClin Study
II: Change of therapeutic plan following advanced diopulmonary monitoring in critically ill patients.

<table>
<thead>
<tr>
<th>Original therapeutic plan</th>
<th>Pursued</th>
<th>Changed</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n=315)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluids</td>
<td>67.6%</td>
<td>32.4%</td>
</tr>
<tr>
<td>Inotropes</td>
<td>78.4%</td>
<td>21.6%</td>
</tr>
<tr>
<td>Vasoconstrictors</td>
<td>77.5%</td>
<td>22.5%</td>
</tr>
<tr>
<td>Diuretics</td>
<td>86.1%</td>
<td>13.9%</td>
</tr>
</tbody>
</table>

Forty-six patients with SAH treated within 24 hours of the ictus were investigated.

A fluid management protocol emphasizing supplemental colloid administration was used to attain the following targets:

- CI - 3.0 L/min/m²
- GEDVi - 700-900 mL/m²
- EVLW < 14 mL/kg
Initially the CI was high (5.3 L/min/m²) and the GEDVi low (555 mL/m²), with elevations of plasma adrenaline, noradrenaline, and cortisol.

Mutoh et al
Guiding therapy by an algorithm based on GEDVI leads to a shortened and reduced need for vaso-pressors, catecholamines, mechanical ventilation, and ICU therapy in patients undergoing cardiac surgery.

Goepfert et al, ICM 2007

Single transpulmonary thermodilution in off-pump coronary artery bypass grafting: haemodynamic changes and effects of different anaesthetic techniques
M Y Kirov1,2, A I Enkin1, V V Kirova1,2, F V Shchurko1,2, V Y Saveliev1,2, V V Bobrov5, I I Chernov4, A N Shokin4 and L I Berntsson3

The use of PiCCO resulted in:
1. Early recognition of hypovolemia and myocardial depression.
2. Better titration of fluid and inotrope/vasopressor therapy.
3. Shorter hospital length of stay after OPCAB.
Targeting EVLW in ARDS

n=101

Ventilation days

<table>
<thead>
<tr>
<th>RHC group</th>
<th>EVLW group</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 days</td>
<td>9 days</td>
</tr>
<tr>
<td>15 days</td>
<td>7 days</td>
</tr>
</tbody>
</table>

ICU days


When EVLW is high

<table>
<thead>
<tr>
<th>Preload status</th>
<th>MAP &lt; 60 or on vasopressors</th>
<th>MAP &gt; 60 mmHg AND off vasopressors</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEDI</td>
<td>C.I. &lt; 2.5</td>
<td>C.I. ≥ 2.5</td>
</tr>
<tr>
<td>&lt;GOAL</td>
<td>Fluid bolus, Dobutamine</td>
<td>Vasopressors Fluid bolus</td>
</tr>
<tr>
<td></td>
<td>Vasopressors</td>
<td></td>
</tr>
<tr>
<td>≥ GOAL</td>
<td>Dobutamine, Vasopressors</td>
<td>KVO IV</td>
</tr>
<tr>
<td></td>
<td>Vasopressors, KVO IV</td>
<td>Diurese, KVO IV</td>
</tr>
</tbody>
</table>

C. Philips et al
“This protocol allows aggressive diuresis of excess preload even during periods of shock – something not done in the FACTT trial and rarely done clinically. This is accomplished by better identifying preload state using superior metrics of preload and cardiovascular status – GEDI, CI, and EVLW.”

C. Philips (with permission)

How should the PiCCO be used?

1. Is there a problem?
2. Identify the problem(s)
3. Which seems to be the most critical problem?
4. Is there a therapeutic conflict?
5. Out of your potential therapeutic options, which decision will cause most/least damage in case of error?
6. Make your decision and follow results
7. Go back to (1)
When do I use the PiCCO?

- CHF + major surgery
- Sepsis
- ARDS, MOF
- Pulmonary edema
- Therapeutic conflicts
- Expected hemodynamic instability

Conclusion

- Critically ill patients do often have complex hemodynamics and may often present us with heart-lung and other therapeutic conflicts.
Clinical examination, vital signs, urine output, Hb, lactate...

Preload & Fluid responsiveness

EVLW

dP/dT, CFI, GEF, PVPI

Cardiac Output

ScvO₂

Thank you!
Cardiac output 6.77 L/min
ScvO₂ is 60%!
Is this CO adequate?

Patient is given dobutamine

CO was high, but not high enough!

The CO and the ScvO₂ complement each other!