Accurate assessment of preload status in the ICU

Why and how?

Prof. Jean-Louis TEBOUL

Medical ICU
Bicetre Hospital
University Paris-South
France
Conflicts of interest

Member of the Medical Advisory Board of Pulsion
Accurate assessment of preload status in the ICU

Why and how?

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Critically ill patients often experience hemodynamic instability

Clinicians are tempted to give fluid to restore adequate hemodynamic conditions

However,

- often, patients have been already resuscitated for several hours or days *(see Rivers et al NEJM 2001)*
- potential volume overload with subsequent risks of pulmonary edema especially in this condition of increased lung permeability
- positive cumulative fluid balance: independent predictor of death
11. We recommend a conservative fluid strategy for patients with established sepsis-induced ARDS who do not have evidence of tissue hypoperfusion (grade 1C).
Critically ill patients often experience hemodynamic instability

Clinicians are tempted to give fluid to restore adequate hemodynamic conditions

However,

- often, patients have been already resuscitated for several hours or days *(see Rivers et al NEJM 2001)*
- potential volume overload with subsequent risks of pulmonary edema especially in this condition of increased lung permeability
- positive cumulative fluid balance: independent predictor of death
- no certainty of fluid responsiveness
<table>
<thead>
<tr>
<th>Source</th>
<th>Patients, No.</th>
<th>FC, No.</th>
<th>Fluid Infused</th>
<th>Volume Infused, mL</th>
<th>Speed of FC, mins</th>
<th>Definition of Response</th>
<th>Rate of Response, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calvin et al²</td>
<td>28</td>
<td>28</td>
<td>5% Alb</td>
<td>250</td>
<td>20–30</td>
<td>ΔSV &gt; 0%</td>
<td>71</td>
</tr>
<tr>
<td>Schneider et al³</td>
<td>18</td>
<td>18</td>
<td>FFP</td>
<td>500</td>
<td>30</td>
<td>ΔSV &gt; 0%</td>
<td>72</td>
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<tr>
<td>Reuse et al⁴</td>
<td>41</td>
<td>41</td>
<td>4.5% Alb</td>
<td>300</td>
<td>30</td>
<td>ΔCO &gt; 0%</td>
<td>63</td>
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<tr>
<td>Magder et al⁵</td>
<td>33</td>
<td>33</td>
<td>9% NaCl</td>
<td>100–950</td>
<td></td>
<td>ΔCO &gt; 250</td>
<td>52</td>
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<tr>
<td>Diebel et al⁶</td>
<td>15</td>
<td>22</td>
<td>R. lactate</td>
<td>300–500</td>
<td></td>
<td>ΔCO &gt; 10%</td>
<td>59</td>
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<tr>
<td>Diebel et al⁷</td>
<td>32</td>
<td>65</td>
<td>R. lactate</td>
<td>300–500</td>
<td></td>
<td>ΔCO &gt; 20%</td>
<td>40</td>
</tr>
<tr>
<td>Wagner and Leatherman⁸</td>
<td>25</td>
<td>36</td>
<td>9% NaCl</td>
<td>938 ± 480</td>
<td>7–120</td>
<td>ΔSV &gt; 10%</td>
<td>56</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>5% Alb, FFP</td>
<td>574 ± 187</td>
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<tr>
<td>Tavernier et al⁹</td>
<td>15</td>
<td>35</td>
<td>HES</td>
<td>500</td>
<td>30</td>
<td>ΔSV &gt; 15%</td>
<td>60</td>
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<tr>
<td>Magder and Lagonidis¹⁰</td>
<td>29</td>
<td>29</td>
<td>25% Alb</td>
<td>100</td>
<td>15</td>
<td>ΔCO &gt; 250</td>
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<tr>
<td></td>
<td></td>
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<td>9% NaCl</td>
<td>150–400</td>
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<tr>
<td>Tosignant et al¹¹</td>
<td>40</td>
<td>40</td>
<td>HES</td>
<td>500</td>
<td>15</td>
<td>ΔSV &gt; 20%</td>
<td>40</td>
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<tr>
<td>Michard et al¹²</td>
<td>40</td>
<td>40</td>
<td>HES</td>
<td>500</td>
<td>30</td>
<td>ΔCO &gt; 15%</td>
<td>40</td>
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<tr>
<td>Feissel et al¹³</td>
<td>19</td>
<td>19</td>
<td>HES</td>
<td>8 mL/kg</td>
<td>30</td>
<td>ΔCO &gt; 15%</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>334</td>
<td>406</td>
<td></td>
<td></td>
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<td>52</td>
</tr>
</tbody>
</table>
Critically ill patients often experience hemodynamic instability.

Clinicians are tempted to give fluid to restore adequate hemodynamic conditions. However,

- often, patients have been already resuscitated for several hours or days.

Can help to choose the **best fluid strategy** by **avoiding** fluid **overload** patients who would be fluid **unresponsive**.

Markers of fluid **responsiveness/unresponsiveness** are required.
| markers of **fluid responsiveness/unresponsiveness** |
Fluid infusion will increase LV stroke volume only if both ventricles are preload responsive.

Fluid responsiveness equivalent to biventricular preload responsiveness.
Accurate assessment of preload status in the ICU

Why and how?

Prof. Jean-Louis TEBOUL
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First, try to perform **echocardiography** to assess cardiac function.

- **Normal cardiac function**
- **Abnormal cardiac function**

**Lung injury?**
ABG, Chest X-ray

- **no**

**Basic monitoring**

- CVC + Art cath
- CVP
- ScvO₂
- AP
- PPV
The lower the CVP, the more likely the presence of preload responsiveness.
A. Initial Resuscitation

1. Protocolized, quantitative resuscitation of patients with sepsis-induced tissue hypoperfusion (defined in this document as hypotension during the first 6 hrs of resuscitation):

   Central venous pressure 8–12 mm Hg

   c) Urine output ≥ 0.5 mL/kg/hr

   d) Central venous (superior vena cava) or mixed venous oxygenation 70% or 65%, respectively (grade 1C).

2. In patients with elevated lactate levels targeting resuscitate lactate (grade 2C).
Cardiac filling pressures are not appropriate to predict hemodynamic response to volume challenge*

David Osman, MD; Christophe Ridel, MD; Patrick Ray, MD; Xavier Monnet, MD, PhD; Nadia Anguel, MD; Christian Richard, MD; Jean-Louis Teboul, MD, PhD

Crit Care Med 2007; 35:64–68
Conclusions: This systematic review demonstrated a very poor relationship between CVP and blood volume as well as the inability of CVP/ΔCVP to predict the hemodynamic response to a fluid challenge. CVP should not be used to make clinical decisions regarding fluid management.
Can dynamic indicators help the prediction of fluid responsiveness in spontaneously breathing critically ill patients?
« static » measures of preload cannot reliably predict fluid responsiveness
Dynamic indices of preload responsiveness

Stroke volume

Ventricular preload

preload responsiveness

preload unresponsiveness

failing heart
First, try to perform **echocardiography** to assess cardiac function.

- **Normal cardiac function**
- **Abnormal cardiac function**

**Lung injury?**
- ABG, Chest X-ray

If **no**, perform **basic monitoring**
- CVC + Art cath
- CVP + AP
- ScvO2 + PPV
Clinical Use of Respiratory Changes in Arterial Pulse Pressure to Monitor the Hemodynamic Effects of PEEP

FREDERIC MICHAUD, DENIS CHEMLA, CHRISTIAN RICHARD, MARC WYSOCKI, MICHAEL R. PINSKY, YVES LECARPENTIER, and JEAN-LOUIS TEBOLI

AM J RESPIR CRIT CARE MED 1999;159:935-939

Relation between Respiratory Changes in Arterial Pulse Pressure and Fluid Responsiveness in Septic Patients with Acute Circulatory Failure

FREDERIC MICHAUD, SANDRINE BOUSSAT, DENIS CHEMLA, NADIA ANGUEL, ALAIN MERCAT, YVES LECARPENTIER, CHRISTIAN RICHARD, MICHAEL R. PINSKY, and JEAN-LOUIS TEBOLI

Am J Respir Crit Care Med 2000,162:134-138

\[ PPV = \frac{PP_{max} - PP_{min}}{(PP_{max} + PP_{min}) / 2} \]

\[ PP_{max} \]

120 mmHg

\[ PP_{min} \]

Arterial Pressure

40
Relation between Respiratory Changes in Arterial Pulse Pressure and Fluid Responsiveness in Septic Patients with Acute Circulatory Failure

FREDERIC MICHAUD, SANDRINE BOUSSAT, DENIS CHEMLA, NADIA ANGUEL, ALAIN MERCAT, YVES LECARPENTIER, CHRISTIAN RICHARD, MICHAEL R. PINSKY, and JEAN-LOUIS TEBOUL

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Relation between Respiratory Changes in Arterial Pulse Pressure and Fluid Responsiveness in Septic Patients with Acute Circulatory Failure

FREDERIC MICHAUD, SANDRINE BOUSSEAT, DENIS CHEMLA, NADIA ANOPOUDI, CHRISTIAN RICHARD, MICHAEL R. PINSKY, and JEAN-LOUIS TEBOUL

Pulse Pressure Variations Follow Artery Bypass Surgery

Andreas Kranz, Paul Kost, et al.

The Influence of Cardiac Output on Fluid Responsiveness

Cyril Charmot, Jean-Xavier Alain, et al.

Arterial Versus Pleural Pressure Responsiveness for Prediction of Fluid Responsiveness in Patients Requiring Thoracic Endotracheal Intubation

Maxime Cannesson, et al.

Evaluation of Stroke Volume Variations Obtained with the Pressure Recording Analytic Method

Matthieu Biais, MD; Vincent Cottenceau, MD; Laurent Steckien, MD; Maylis Jean; Laetitia Ottolenghi, MD; Stéphanie Rouillet, MD; Alice Quinter, MD; François Sztark, MD, PhD

Predictive Value of Pulse Pressure Variation for Fluid Responsiveness in Septic Patients Using Lung-Protective Ventilation Strategies


Pulse Pressure Variation Predicts Fluid Responsiveness During Heart Displacement for Off-Pump Coronary Artery Bypass Surgery

Jaehyun Lee, MD, PhD; Yuseok Jeon, MD, PhD; Jay-Hyon Bahk, MD, PhD; Nam-Su Gil, MD, PhD; Kim, MD, PhD; Deok Man Hong, MD, PhD; and Hyun Joo Kim, MD

Stroke Volume and Pulse Pressure Variations for Prediction of Fluid Responsiveness in Patients Undergoing Off-Pump Coronary Artery Bypass


Correspondence

X. Monnet1,2*, L. Guerin1,2, M. Joziak1,2, A. Bataille1,2, F. Julien1,2, C. Richard1,2, J-L Teboul1,2

A. Derichard1, E. Robin1, B. Tavernier1, M. Costecalde1, M. Fleyfel1, J. Onimus1, G. Leballe1, J-P. Chambon2 and B. Valtat1

Limitations of PPV

- impossible to interpret in pts with **spontaneous breathing activity**
- impossible to interpret in patients with **arrhythmias**
- difficult to interpret if **tidal volume** is too low
- difficult to interpret if **lung compliance** is too low
- difficult to interpret in case of **high frequency ventilation**
Patient with circulatory failure

First, try to perform **echocardiography** to assess cardiac function

- **Normal cardiac function**
- **Abnormal cardiac function**

**Lung injury?**
ABG, Chest X-ray

- **no**
- **yes**

**basic monitoring**

- only
- CVC + Art cath
- CVP
- AP
- ScvO₂
- PPV considered valid
First, try to perform **echocardiography** to assess cardiac function.

**Normal cardiac function**

**Abnormal cardiac function**

**Lung injury?**
ABG, Chest X-ray

- **no**

**basic monitoring**
only

- **CVC** + **Art cath**
- **CVP**
- **ScvO₂**

- **yes**
- **no**

**uncalibrated CO monitoring**

- **PPV/SVV**

**CO response to:**
- **PLR test**

**PPV considered valid**
Hemodynamic parameters to guide fluid therapy

Paul E Marik¹, Xavier Monnet², Jean-Louis Teboul²

[Diagram showing passive leg raising and transfer of blood from the legs and abdominal compartments]
Passive leg raising
PLR mimics fluid challenge

Unlike fluid challenge, no fluid is infused, and the effects are reversible and transient.

The hemodynamic response to PLR can predict the hemodynamic response to volume infusion.
The hemodynamic response to PLR can predict the hemodynamic response to fluid infusion.
### PLR-induced changes in CO

<table>
<thead>
<tr>
<th>Study name</th>
<th>sample size</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monnet CCM 2006</td>
<td>71</td>
<td>0.96</td>
</tr>
<tr>
<td>Lafanéchère CC 2006</td>
<td>22</td>
<td>0.95</td>
</tr>
<tr>
<td>Lamia ICM 2007</td>
<td>24</td>
<td>0.96</td>
</tr>
<tr>
<td>Maizel ICM 2007</td>
<td>34</td>
<td>0.89</td>
</tr>
<tr>
<td>Monnet CCM 2009</td>
<td>34</td>
<td>0.94</td>
</tr>
<tr>
<td>Thiel CC 2009</td>
<td>102</td>
<td>0.89</td>
</tr>
<tr>
<td>Biais CC 2009</td>
<td>30</td>
<td>0.96</td>
</tr>
<tr>
<td>Preau CCM 2010</td>
<td>34</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td><strong>351</strong></td>
<td><strong>0.95</strong></td>
</tr>
</tbody>
</table>

Diagnostic accuracy of passive leg raising for prediction of fluid responsiveness in adults: systematic review and meta-analysis of clinical studies
Patient with circulatory failure

First, try to perform **echocardiography** to assess cardiac function

- **Normal** cardiac function
- **Abnormal** cardiac function

**Lung injury?**
- ABG, Chest X-ray

**no**

- **basic monitoring** only
  - CVC + Art cath
  - CVP + AP
  - ScvO\(_2\)

**yes**

- PPV/SVV
  - CO response to:
    - PLR test
    - EEO test

**no**

- **uncalibrated CO monitoring**
  - PPV considered valid
End-expiratory occlusion test

Cyclic decrease in preload

Transient increase in preload and hence in CO in case of preload-dependency

Fluid responders should be identified by an increase of their CO during the end-expiration occlusion test
Predicting volume responsiveness by using the end-expiratory occlusion in mechanically ventilated intensive care unit patients

Xavier Monnet, MD, PhD; David Orman, MD; Christophe Riethl, MD; Bouchra Lamia, MD; Christian Richard; MPH; Jean-Louis Teboul, MPH, PhD

Crit Care Med 2009; 37:951-956
Patient with circulatory failure

First, try to perform **echocardiography** to assess cardiac function.

**Normal cardiac function**

**Abnormal cardiac function**

**Lung injury?**
ABG, Chest X-ray

- no
- yes

**Basic monitoring**
CVC + Art cath
CVP, ScvO₂

**Advanced monitoring**
uncalibrated CO monitoring
PAC
CO
PAOP
PAP
PVPI, PPV, SVV
GEDV, CFI, EVLW
SvO₂
ScvO₂

**PPV/SVV**
CO response to:
- PLR test
- EEO test

**Considered valid**
GEDV
marker of
cardiac preload
Global End-Diastolic Volume as an Indicator of Cardiac Preload in Patients With Septic Shock*

Frédéric Michard, MD, PhD; Sami Alaya, MD; Véronique Zarka, MD; Mabrouk Bahoul, MD; Christian Richard, MD; and Jean-Louis Teboul, MD, PhD

Chest 2003; 124:1900-1908

GEDV behaves as a marker of preload

Changes in CO
Changes in GEDV

fluid loading
dobutamine
Cardiac function index (CFI) = CO/GEDV
EVLW
quantitative measure
of pulmonary edema
Multivariable stepwise logistic regression analysis with Day-28 mortality as the dependant factor

<table>
<thead>
<tr>
<th></th>
<th>Odds Ratio ( CI 95%)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal blood lactate</td>
<td>1.29 (1.14 - 1.46)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Mean PEEP</td>
<td>0.78 (0.67 – 0.91)</td>
<td>0.002</td>
</tr>
<tr>
<td>Minimal PaO$_2$ / FiO$_2$</td>
<td>0.98 (0.97 - 0.99)</td>
<td>0.006</td>
</tr>
<tr>
<td>SAPS II</td>
<td>1.03 (1.01 - 1.05)</td>
<td>0.02</td>
</tr>
<tr>
<td>$EVLW_{max}$</td>
<td><strong>1.07</strong> (1.02 - 1.12)</td>
<td><strong>0.007</strong></td>
</tr>
<tr>
<td>Mean fluid balance</td>
<td>1.0004 (1.0001 – 1.0008)</td>
<td>0.02</td>
</tr>
</tbody>
</table>
EVLW

Safety parameter
during
fluid management
Cumulative fluid balance (L)

* p < 0.0001 vs temps 0

PAOP group

EVLW group
Improved Outcome Based on Fluid Management in Critically Ill Patients Requiring Pulmonary Artery Catheterization\textsuperscript{1-3}

JOHN P. MITCHELL, DAN SCHULLER, FRANK S. CALANDRINO, and DANIEL P. SCHUSTER\textsuperscript{4}

AM REV RESPIR DIS 1992; 145:990–998
PVPI = EVLW/Pulmonary blood volume

PVPI

marker of

lung μvessels permeability
Assessing pulmonary permeability by transpulmonary thermodilution allows differentiation of hydrostatic pulmonary edema from ALI/ARDS.

Cut-off value = 3
Se = 85%
Sp = 100%
Assessing pulmonary permeability by transpulmonary thermodilution allows differentiation of hydrostatic pulmonary edema from ALI/ARDS

PVPI

BNP

p < 0.05

sensitivity

100 - specificity
Volumetric monitoring systems

Useful for **guiding fluid management**
especially in patients with **lung injury** and **circulatory shock**

- **SVV/PPV** or **PLR** or **EEO** test for predicting **volume responsiveness**
- **GEDV** for checking that **preload increases** with fluid
- **Pulse Contour CO** for evaluating the **actual response** to fluid
- **EVLW** and **PVPI** for judging **lung tolerance** to fluid infusion

<table>
<thead>
<tr>
<th>Decision</th>
<th>to start</th>
<th>to continue fluid infusion</th>
<th>to stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVV/PPV, PLR, EEO</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>GEDV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EVLW/PVPI</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
because the situation can **evolve** in a bad way
you also can use a **stepwise** approach

---

**Patient with circulatory failure**

---

ABG, Chest X-ray

**no**

**basic monitoring**

---

**yes**

**uncalibrated CO monitoring**

---

**no**

**advanced monitoring**

---

**yes**

**PPV/SVV**

**CO response to:**
- PLR test
- EEO test

---

**CVC + CVP**

**Art cath**

---

**AP**

**PPV**

**considered valid**

---

**PAC**

**CO**

**PAOP**

**PAP**

**SvO₂**

---

**PiCCO₂**

**CO**

**GEDV, CFI, EVLW, PVPI, PPV, SVV, ScvO₂**

---

**Thank you**