Monitoring Fluid Responsiveness Non-Invasively

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Sheba Medical Center, Tel Aviv University, Israel

CCCF Toronto 2015
Disclosure

The speaker consults to
Masimo (USA) and Pulsion (Germany)
“The pattern of many important but stalled ideas is that they attack problems that are big but, to most people, invisible.”
One big problem that has been invisible to most people for a long time

- Fluids are a drug

“IV fluids, the most commonly used drug in the hospital, are a double-edged sword.”

Kenneth A. Kudsk,

Annals of Surgery • Volume 238, Number 5, November 2003
A positive fluid balance was independently associated with an increase in the risk of death.

Fluid overload was an independent risk factor for the incidence of AKI and increased the severity of AKI.
Fig. 1 The art of fluid management: Walking the fine line between the dangers of fluid overload and hypovolemia.
Another big problem that has been invisible to most people for a long time

- Fluids are a drug
- It is not easy to correctly determine fluid needs
The left ventricular function (Frank-Starling) curve
A “perfectly-measured” preload

Stroke volume  

Good ventricular function

Poor ventricular function

Cardiac preload
Fluid Responsiveness is the degree by which the CO responds to a modification of preload.
The majority of the parameters that are used to guide fluid administration are poor predictors of FR.
Predicting fluid responsiveness in patients undergoing cardiac surgery: functional haemodynamic parameters including the Respiratory Systolic Variation Test and static preload indicators

S. Preisman*, S. Kogan, H. Berkenstadt and A. Perel†
Preload measurement alone should not be used to predict fluid responsiveness.

We recommend a fluid challenge to predict fluid responsiveness.
Volume expansion-induced changes in arterial pressure have low discriminative power of to detect an increase of > 15% of cardiac output after volume expansion.
Changes in mean arterial pressure or in pulse pressure do not reliably track changes in cardiac index after fluid challenge in patients with septic shock.
More than 50% of patients in which fluid loading is considered to be “clinically indicated” are ‘non-responders’ and are being loaded with fluids unnecessarily!

Critical Care Review

Predicting Fluid Responsiveness in ICU Patients*
A Critical Analysis of the Evidence
Frédéric Michard, MD, PhD; and Jean-Louis Teboul, MD, PhD

Fluid Therapy in Resuscitated Sepsis
Less Is More
(CHEST 2008; 133:252–263)
Lakshmi Durairaj, MD; and Gregory A. Schmidt, MD, FCCP

Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature*
(Crit Care Med 2009; 37:2642–2647)
Paul E. Marik, MD, FCCM; Rodrigo Cavallazzi, MD; Tajender Vasu, MD; Amyn Hirani, MD
60 patients who required fluid challenge due to suspicion of hypovolemia on the basis of tachycardia, hypotension, oliguria or cutaneous vasoconstriction.

Fluid challenge was performed over 30 min with 1,000 ml crystalloids or 500 ml of hydroxyethylstarch.

There were 33 (55%) fluid responders and 27 (45%) non-responders.
Of the 402 patients included in the study, volume expansion (500 ml of colloid solution given over 10-20 min) increased CO by more than 15% in 205 patients (51%).
A fluid challenge identifies and simultaneously treats volume depletion, whilst avoiding deleterious consequences of fluid overload through its small volume and targeted administration.

Continuous cardiac output monitoring is the gold standard to monitor the response to a fluid challenge.
Hypotension is still the main indication for a FC.

Practice of FC is highly variable.

No monitoring (to assess indication or impact).

Information from previous failed FCs is not always taken into account.
Many of the most recent perioperative GDT studies have failed to improve outcome because they were based on CO/SV maximization without taking into account fluid responsiveness.
**CardioQ Quick Reference Guide**

**Surgical Application - Interpreting results**

1. **STROKE VOLUME OR STROKE DISTANCE OPTIMISATION**
   - Monitor SV/SD & FTc

2. **200ML COLLOID CHALLENGE OVER 5 MINS.**
   - SV/SD INCREASE >10% → YES
   - SV/SD DECREASE >10% → NO
   - Monitor SV/SD & FTc

3. **PRELOAD**
   - Heart rate
   - Afterload

4. **Contractility**
Individualised oxygen delivery targeted haemodynamic therapy in high-risk surgical patients: a multicentre, randomised, double-blind, controlled, mechanistic trial

Gareth L Ackland, Sadaf Iqbal, Laura Gallego Paredes, Andrew Toner, Craig Lyness, Nicholas Jenkins, Phoebe Bodger, Shamir Karmali, John Whittle, Anna Reyes, Mervyn Singer, Mark Hamilton, Maurizio Ceconi, Rupert M Pearse, Susan V Mallett, Rumana Z Omar, for the POM-O (PostOperative Morbidity-Oxygen delivery) study group*

*Lancet Respir Med 2015; 3: 33-41*

<table>
<thead>
<tr>
<th></th>
<th>Control (n=92)</th>
<th>Goal-directed therapy (n=95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APACHE II score on intensive care unit admission</td>
<td>16 (5)</td>
<td>15 (6)</td>
</tr>
<tr>
<td>Crystalloid (mL/kg per h)</td>
<td>1.0 (1.0-1.1)</td>
<td>1.0 (1.0-1.2)</td>
</tr>
<tr>
<td>Colloid (mL/kg per h)</td>
<td>1.4 (0-2.8)</td>
<td>2.9 (1.7-3.6)</td>
</tr>
<tr>
<td>Blood transfusion</td>
<td>11 (12%)</td>
<td>22 (23%)</td>
</tr>
<tr>
<td>Dobutamine infusion</td>
<td>0</td>
<td>38 (40%)</td>
</tr>
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</table>
Effect of a Perioperative, Cardiac Output-Guided Hemodynamic Therapy Algorithm on Outcomes Following Major Gastrointestinal Surgery: A Randomized Clinical Trial and Systematic Review

JAMA. Published on line May 19, 2014.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Cardiac Output-Guided Hemodynamic Therapy Algorithm (n = 367)</th>
<th>Usual Care (n = 362)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intravenous crystalloid, median (IQR), mL</td>
<td>1000 (459-2000)</td>
<td>2000 (1283-3000)</td>
</tr>
<tr>
<td>During surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During 6 h following surgery</td>
<td>506 (410-660)</td>
<td>600 (450-800)</td>
</tr>
<tr>
<td>Intravenous colloid, median (IQR), mL</td>
<td>1250 (1000-2000)</td>
<td>500 (0-1000)</td>
</tr>
<tr>
<td>During surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During 6 h following surgery</td>
<td>500 (250-1000)</td>
<td>0 (0-500)</td>
</tr>
</tbody>
</table>
Sub-study of the OPTIMISE trial including 100 of the original 368 patients enrolled in the intervention group.

Intervention included 3 fluid challenges (250 ml colloid) during surgery and 3 after surgery.

556 fluid challenges were administered and 159 (28.6%) were associated with increased stroke volume.
The hemodynamic protocol was based on SV optimization alone (250 ml boluses for any > 10 % decrease in SV) following the protocol recommended by UK’s NHS.

However, the feedback from anesthesiology providers was that this protocol was forcing them to administer more fluids than they would feel comfortable administering and the team leaders decided to include stroke volume variation (SVV) as the trigger for fluid administration in order to increase the buy-in from clinicians.
Fluid responsiveness can be assessed by the response of the SV to the transient decrease in the venous return with every mechanical breath.
Fluid responsiveness can be assessed by the response of the SV to the transient decrease in the venous return with every mechanical breath.
Respiratory variations in the arterial pressure during mechanical ventilation reflect volume status and fluid responsiveness
Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature*  

Crit Care Med 2009; 37:2642–2647

Paul E. Marik, MD, FCCM; Rodrigo Cavallazzi, MD; Tajender Vasu, MD; Amyn Hirani, MD

<table>
<thead>
<tr>
<th>Correlation (r)</th>
<th>AUC</th>
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<tbody>
<tr>
<td>PPV</td>
<td>.78 (.74–.82)</td>
</tr>
<tr>
<td>SPV</td>
<td>.72 (.65–.77)</td>
</tr>
<tr>
<td>SVV</td>
<td>.72 (.66–.78)</td>
</tr>
<tr>
<td>LVEDAI</td>
<td>—</td>
</tr>
<tr>
<td>GEDVI</td>
<td>—</td>
</tr>
<tr>
<td>CVP</td>
<td>.13 (−.01–.28)</td>
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</tbody>
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Predicting fluid responsiveness in patients undergoing cardiac surgery: functional haemodynamic parameters including the Respiratory Systolic Variation Test and static preload indicators†

S. Preisman*, S. Kogan, H. Berkenstadt and A. Perel‡
A decrease in PPV of ≥3% following VE allowed detecting an increase (>15%) in CO with a sensitivity of 90% and a specificity of 77%.
The PPV serves not only to predict fluid-responsiveness but also to assess the response of the CO to a fluid challenge.
Decrease in pulse pressure and stroke volume variations after mini-fluid challenge accurately predicts fluid responsiveness

BJA Advance Access published July 6, 2015

J. Mallat¹*, M. Meddour¹, E. Durville¹, M. Lemyze¹, F. Pepy¹, J. Temime¹, N. Vangrunderbeeck¹, L. Tronchon¹, D. Thevenin¹ and B. Tavernier²
Non-invasive measurement of pulse pressure variation and systolic pressure variation using a finger cuff corresponds with intra-arterial measurement

B. Lansdorp¹,²*, D. Ouweneel¹, A. de Keijzer¹, J. G. van der Hoeven², J. Lemson² and P. Pickkers²


Prediction of fluid responsiveness by a continuous non-invasive assessment of arterial pressure in critically ill patients: comparison with four other dynamic indices

X. Monnet¹,²*, M. Dres¹,², A. Ferré¹,², G. Le Teuff⁴, M. Jozwiak¹,², A. Bleibtreu¹,², M.-C. Le Deley⁴, D. Chemla¹,³, C. Richard¹,² and J.-L. Teboul¹,²

SVC collapsibility index
Vieillard-Baron A et al, Anesthesiology 2001; 95:1083-8
Vieillard-Baron A et al, AJRCCM 2003; 168: 671-6

Respiratory variations in IVC diameter
Feissel M et al, Int Care Med 2004; 30: 1834-7

Respiratory variations in aortic blood flow velocity
Feissel M et al, Chest 2001; 119: 867-873

Respiratory variations in aortic velocity-time integral

Respiratory variations in mitral Doppler indices

The respiratory change in preejection period
Bendjelid K et al, J Appl Physiol 2004; 96: 337-42
PVI = Pleth Variation Index

\[ PVI = \frac{P_{I_{\text{MAX}}} - P_{I_{\text{MIN}}}}{P_{I_{\text{MAX}}}} \]
A higher PVI = More likely to respond to fluid administration
A higher PVI is correlated with a greater response of the CI to volume expansion.
The use of PVI-based protocols led to a significantly decreased intraoperative net fluid balance.

Goal-Directed Fluid Management Based on the Pulse Oximeter–Derived Pleth Variability Index Reduces Lactate Levels and Improves Fluid Management

Patrice Forget, MD,* Fernande Lois, MD,* and Marc de Kock, MD, PhD*

(Anesth Analg 2010; 111:910–4)

Pleth variability index-directed fluid management in abdominal surgery under combined general and epidural anesthesia

Yinan Yu · Jing Dong · Zifeng Xu · Hao Shen · Jijian Zheng

J Clin Monit Comput
Published online: 21 February 2014

Standardization of Care: Impact of an Enhanced Recovery Protocol on Length of Stay, Complications, and Direct Costs after Colorectal Surgery

Robert H Thiele, MD, Kathleen M Rea, MSN, APRN, Florence E Turrentine, PhD, RN, Charles M Friel, MD, FACS, Taryn E Hassinger, MD, Bernadette J Goudreau, BS, Bindu A Umapathi, MD, Irving L Kron, MD, FACS, Robert G Sawyer, MD, FACS, Traci L Hedrick, MD, FACS, Timothy L McMurry, PhD

PVI-based protocol decreased intra-operative net fluid balance from 2733 to 848 mL (p < 0.0001).
The “Gray Zone” of the PVI

Feissel M, et al. ICM 2007

Loupec T, et al. CCM 2011
Randomized controlled trial of stroke volume optimization during elective major abdominal surgery in patients stratified by aerobic fitness

C. W. Lai¹,³, T. Starkie², S. Creanor³, R. A. Struthers²,³, D. Portch⁴, P. D. Erasmus², N. Mellor¹, K. B. Hosie¹, J. R. Sneyd²,³ and G. Minto²,³,*


**SVV > 10%**

<table>
<thead>
<tr>
<th>Intraoperative fluids (ml)*</th>
<th>Control (n=111)</th>
<th>SVO (n=109)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalloid</td>
<td>4142 (1393)</td>
<td>4043 (1538)</td>
<td>0.59</td>
</tr>
<tr>
<td>Colloid</td>
<td>390 (655)</td>
<td>370 (700)</td>
<td>0.89</td>
</tr>
<tr>
<td>Investigator colloid</td>
<td>0</td>
<td>956 (896)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total intraoperative fluids (ml)*</td>
<td>4532 (1525)</td>
<td>5369 (2270)</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Limitations and confounding factors of functional hemodynamic parameters

1. Spontaneous breathing
2. Non-sinus rhythm
3. Tidal volume / airway pressure
4. Right heart failure
5. Inherent inaccuracies
6. Different proprietary algorithms
Excessive respiratory variation in the Pleth signal is the most sensitive sign of upper airway obstruction in spontaneously breathing patients.
The post ectopic beat reflects the response of the LV to increased preload (due to a longer filling time) offering a "free" prediction of fluid responsiveness.
Pleth variability index is a weak predictor of fluid responsiveness in patients receiving norepinephrine

X. Monnet¹,²*, L. Guérin¹,², M. Jozwiak¹,², A. Bataille¹,², F. Julien¹,², C. Richard¹,² and J.-L. Teboul¹,²


PVI was less reliable than PPV and SVV for predicting fluid responsiveness in critically ill patients receiving norepinephrine.
Noninvasive Hemodynamic Monitoring

No High Heels on the Farm; No Clogs to the Opera

Cannesson M, Le Manach Y. Anesthesiology 2012; 117:937–9

“... choosing the most appropriate hemodynamic monitor is context dependent.”
Figure 2 Possible choice of monitoring system in relation to a patient's degree of perioperative risk. CO, cardiac output; PAC, pulmonary artery catheter; PPV, pulse pressure variation; ScvO₂, central venous oxygen saturation.
## HOW TO ASSESS FLUID RESPONSIVENESS?

**CD**  
Thematic Session

<table>
<thead>
<tr>
<th>Venue: Berlin</th>
<th>Time: Monday 5 October, 14:15 – 15:45</th>
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Chair: Jean-Louis Teboul, France  
Chair: Michael Pinsky, United States

<table>
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<tr>
<th>...from a fluid challenge</th>
<th>Jean-Louis Vincent, Belgium (confirmed)</th>
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<tbody>
<tr>
<td>Discussion</td>
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<tr>
<th>...from the arterial pressure curve</th>
<th>Azriel Perel, Israel (confirmed)</th>
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<tbody>
<tr>
<td>Discussion</td>
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<tr>
<th>...from the passive leg raising test</th>
<th>Xavier Monnet, France (confirmed)</th>
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<tbody>
<tr>
<td>Discussion</td>
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<tr>
<th>...from the end-expiratory occlusion test</th>
<th>Jean-Louis Teboul, France (confirmed)</th>
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<tr>
<td>Discussion</td>
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<tr>
<th>...by echocardiography</th>
<th>Michel Slama, France (confirmed)</th>
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<tbody>
<tr>
<td>Discussion</td>
<td></td>
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</table>
The PLR effects must be assessed by a direct and continuous measurement of cardiac output and not by the simple measurement of blood pressure.
End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test.
End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test

Intensive Care Med. 2013 Jan;39(1):93-100
End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test

Intensive Care Med. 2013 Jan;39(1):93-100
the PLR effects must be assessed by a direct and continuous measurement of cardiac output and not by the simple measurement of blood pressure.

Pain, cough, discomfort, and awakening could provoke adrenergic stimulation, resulting in mistaken interpretation of cardiac output changes.
An end-expiratory 15 sec occlusion prevents the cyclic impediment in left cardiac preload and may act like a fluid challenge.
Non-Responder?

"Responder"

"Non-Responder"

Stroke volume

Preload
“The presence of fluid-responsiveness is not an absolute indication to give fluids, and the final decision has to take into account the apparent need for hemodynamic improvement and the associated risk.”
Conclusions:

- The assessment of fluid responsiveness (FR) is crucial for effective and safe fluid management.
- In mechanically ventilated patients, FR can be assessed by functional hemodynamic parameters, but only when appropriate.
- Other preload-modifying maneuvers, including a small and fast fluid challenge or passive leg raising, are useful especially when combined with a continuous measurement of CO.
- The presence of FR is not an absolute indication to administer fluids.

Thank you for your attention!