Clinical Applications of The Pleth. Variability Index (PVI):

A non invasive and continuous monitoring of fluid responsiveness

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Preoperative hypovolemia after an overnight fasting period does not occur regularly in all patients. Fluid reloading is unjustified, at least in cardiovascular healthy patients before low-invasive surgery.

Fluid loss from insensible perspiration is overestimated in many patients, a loss of only 1 ml/kg per hour occurs even when the abdominal cavity is opened.
Where is the « Third Space »?

« Eradicating this notion from our minds could be a further key to achieving perioperative fluid optimisation » Jacob et al. 2009
Starling Law = Glycocalyx

\[ J_e = K_f (P_e - P_l) - \sigma (\pi_e - \pi_h) \]
Atrial Natriuretic Peptide Induces Shedding of Endothelial Glycocalyx

Intravascular Volume Effect of IV Fluids

*Jacob et al. 2007; Lancet 369: 1984-6*

**Crystalloids vs Colloids:**
only if glycocalyx intact

**The Context Sensitivity of Colloidal Volume Effects**

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[Diagram: The Crystalloids vs Colloids Controversy: The Facts]

**Fig. 3.** The context sensitivity of volume effects of iso-oncotic colloids: while 5% hydroxyethylstarch or 5% human albumin remain within the circulation to almost 100% if infused as a substitute during acute blood loss (left-hand column), the preparations vanish out of the vasculature to a large extent if applied as a hypervolaemic bolus (right-hand column). Drawn schematically according to Jacob et al. (2007, Lancet 369: 1984–1986) with permission.
Fig 1 Curve A represents the hypothesized line of risk. Broken line B represents a division between patient groups in a 'wet vs dry' study. Broken line C represents a division between patient and groups in an 'optimized vs non-optimized' study.

Why Not Give Volume to Every Unstable Patient as Primary Resuscitation Therapy?

<table>
<thead>
<tr>
<th>Responders / Non-Responders</th>
<th>% Responders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calvin (Surgery 91)</td>
<td>20 / 8</td>
</tr>
<tr>
<td>Schneider (Am Heart J 89)</td>
<td>13 / 5</td>
</tr>
<tr>
<td>Reuse (J Chest 90)</td>
<td>26 / 15</td>
</tr>
<tr>
<td>Magder (J Crit Care 92)</td>
<td>17 / 16</td>
</tr>
<tr>
<td>Diebel (Arch Surgery 92)</td>
<td>13 / 9</td>
</tr>
<tr>
<td>Diebel (J Trauma 54)</td>
<td>26 / 39</td>
</tr>
<tr>
<td>Wagner (J Chest 98)</td>
<td>20 / 16</td>
</tr>
<tr>
<td>Tavernier (Annesthesia 98)</td>
<td>21 / 14</td>
</tr>
<tr>
<td>Magder (J Crit Care 99)</td>
<td>13 / 16</td>
</tr>
<tr>
<td>Tousignant (Annalg 00)</td>
<td>16 / 24</td>
</tr>
<tr>
<td>Michard (Am J 104)</td>
<td>16 / 24</td>
</tr>
<tr>
<td>Feissel (J Chest 01)</td>
<td>10 / 9</td>
</tr>
</tbody>
</table>

Mean 211 / 195 52%
Strategies for Volume Replacement


• « Restrictive » strategies were compared with « permissive » or « liberal » ones.


But:

– Commonly accepted definition of « restrictive » or « liberal » fluid strategies do not exist, making those studies not comparable
– Endpoints varied from PONV to pain, tissue oxygenation or bowel recovery time, which de facto rules out a comparison

• All those studies have in common that no hemodynamic goal were set which is in contrast with « goal-directed-therapy approaches »
Goals & Strategies for Volume Replacement

*Strunden et al. Annals of Intensive Care 2011; 1: 2-8*

- The primary goal of the cardiovascular system is to supply adequate amount of oxygen to the body and match its metabolic demand. Hypovolemia as well as hypervolemia decreases tissue perfusion. *Intensive Care Med 2011; 37: 52-9.*


- How can cardiac output (CO) as the main determinate of oxygen delivery, be improved?
Endpoint of Volume Expansion?

Preload-responsiveness = CO can be improved by VE
If Preload is optimal, one can assume that no ANP is released

- **Cardiac Output (CO):**
  - $\Delta CO = \text{Heart Rate} \times \Delta \text{Stroke Volume}$
  - HR in beats/min
  - SV = ml/beat
  - Normal CO: 4-6 L/min

- **Cardiac Index = CO/BSA**
  - Normal CI: 2.5-4 L/min/M$^2$

- **SV = EDV – ESV**
- **SVI = SV/BSA**
- **EF = SV/EDV \times 100**
  - Normal EF: 40-60%

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The impact of fluid therapy on the microcirculation. Fluid administration is the therapy of choice following shock. The amount and/or composition of the fluids, however, can either have beneficial or deleterious effects on the microcirculation.
Neither CVP or Ppa reflect Ventricular Volumes or Tract Preload-Respondiveness

Kumar et al. Crit Care Med 32:691-9, 2004
Starling’s Law of the Heart Lives!

Kumar et al. Crit Care Med 32:691-9, 2004
PPV and SVV Predict Preload-Responsiveness

The Magnitude of the Change in Stroke Volume/Pulse Pressure Due to Positive Airway Pressure is an Indicator of Bi-ventricular Preload Dependency

Pulse Pressure Relationship to Stroke Volume

- On a beat to beat basis, changes in pulse pressure must relate to changes in stroke volume.
Stroke Volume Variation During Mechanical Ventilation

The Heart is a Pressure Chamber within a Pressure Chamber

Figure 1. The heart and lungs are pump oxygenators located within the thoracic cage. The pump receives blood from a low pressure venous reservoir and expels the blood to a high pressure arterial reservoir outside of the chest.

The Venous Return Curve

\[ VR = CO = \frac{(P_{ms} - P_{ra})}{RVR} \]

Slope = \( \frac{1}{RVR} \)

\[ P_{ra} = P_{hrs} \]

Guyton (Am J Physiol 1957)
The Venous Return Curve

Guyton (Am J Physiol 1957)
Matching of the Venous Return Curve with the Cardiac Function Curve

Cardiac Output

Equilibrium Point

Venous Return

\[ Q \text{ (l/min)} \]

\[ P_{ra} \text{ (mm Hg)} \]

0

10
Effect of Intrathoracic Pressure on Venous Return

Blood Flow (L/min)

Right Atrial Pressure (mm Hg)

- Increased ITP
- Volume Infusion

Points A, B, C indicate different pressure-flow relationships.
Right Heart ➔ Left Heart

- Rise of pleural pressure impedes venous return to the RA ➔ Decreased in RV stroke volume (occurs immediately: one heart beat)
- Transit time in pulmonary vessels = 3,6 heart beats ➔ Decreased LV preload ➔ Decrease in LV stroke volume

De Backer et al. Anesthesiology 2009;110: 1092-7

- (Increase in ITP decrease LV afterload)

Δ PP & Δ SP are Surrogate Measures of Δ SV


• Δ SV = resp. change in stroke volume
• Δ PP = resp. change in (PP max – PP min)/(PP mean)
• Δ SP = resp. change in systolic pressure
• Endpoint: Δ CI > 15%
• Δ PP best; Δ PP > 13% is 94% sensit. and 96% spec. to detect VE responsiveness
  – Δ PP reflects changes in stroke volume better than Δ SP because transmural pressure (pleural pressure) affects both systolic and diastolic pressures
Relation between Respiratory Change in Pulse Pressure and Fluid Responsiveness in Septic Patients with acute Circulatory Failure


![Graph showing ROC curves comparing the ability of ΔPp, ΔPs, Pra, and Ppao to discriminate responder (CI increase > 15%) and nonresponder patients to VE. The area under the ROC curve for ΔPp was greater than for ΔPs, Pra, and Ppao (p < 0.01).](image)

![Graph showing relationship between ΔPp before VE (Baseline ΔPp) and the VE-induced changes in CI. (Upper panel) Relationship between ΔPs before VE (Baseline ΔPs) and the VE-induced changes in CI. (Dotted line = identity line).](image)
CONVENTIONAL PULSE OXIMETRY

The conventional "red over infrared" approach measures the differential optical density of red (R) and infrared (IR) light as projected through a vascular bed and calculates a ratio (r) of the optical densities. Utilizing the optical density ratio, an arterial oxygen saturation ($\text{SpO}_2$) value is empirically reported based on the ratio obtained.

![Diagram of pulse oximetry](image)

**Fig. 15.2** Absorption in different tissue components by light of a pulse oximeter.

**Discrete Saturation Transformation (DST*) Algorithm**

- Reference Signal Generator
- Reference Signal
- Adaptive Filter
- ANC output power

$\text{SpO}_2 = 95\%$ (range 1-100%)
Perfusion Index (PI)  

PlethVариability Index (PVI)

**Equation 1**  
\[ \text{PI} = \frac{\text{AC}}{\text{DC}} \times 100\% \]

**Equation 2**  
\[ \text{PVI} = \frac{\text{PI}_{\text{Max}} - \text{PI}_{\text{Min}}}{\text{PI}_{\text{Max}}} \times 100\% \]
PVI (ΔPI) is a Surrogate Measure of ΔPP

- Cannesson et al, Crit care 2005
- Natalini et al, Anesthesiology 2006
- Solus et al, B J Anaesth 2006
- Zimmermann et al, Eur J Anaesthesiol 2010
- Cannesson et al, B J Anaesth 2008
  - PVI > 13 predicts fluid responsiveness
Pleth Variability Index
Pleth. Variability Index (PVI)

• **How to do it?**
  – Volume expansion if PVI > 13 ➔ VE until PVI 10-13
    • Preload responsiveness at PVI >13 with 100% Sens. & 81% Specif.

  *But...About Ventilation:*

• Requires positive-pressure ventilation
  – Keep RF at 12 or less (nextslide)
  *De Backer et al. Anesthesiology 2009;110: 1092-7*

• If thorax is open, PVI is influenced by pre-load but not by ventilation
  *Sander et al. Crit Care 2007; 11: R 121*

• A high PEEP will influence CO
Influence of RR on Left SV Variations

- As the circulation is pulsatile, Pulmonary transit time is dependent on the HR (3,6 beats) not the RR

- In high RR, R SV variations are preserved but not L SV variations: the influence of positive ventilation pressure is blured during pulmonary transit time

- HR/RR < 3,6 ➞ RR should be 12/min. or less

*De Backer et al. Anesthesiology* 2009;110: 1092-7
Pleth Variability Index (PVI)

*But... About Value of the Signal, Software Calculations:*

- Requires ± 2 minutes (calculation of mean PVI on n resp. cycles)
- Requires more time to have a stable value when starting to measure
- Requires PI > 0.5 cf: PVI does not reflect ventilation related variability of PI if low perfusion in the periphery.
- Accuracy of PVI is influenced by the quality of PI (4% or more are best)

But...About Adult vs. Small and Big Children:

• Not for children, why?
  – In infants, the cardiac muscle is immature and there is a very low reserve of contractility. The most efficient way to increase CO is to increase the heart rate. The very young heart is chronotropic dependent and afterload dependent.
  
  – The intravascular compliance is higher in kids than in adults (diastolic arterial pressure tends to be lower while diastolic pressure tends to be higher, best to use mean art. pressure).
  
  – The few studies in children demonstrate that SVV is a strong predictor of fluid responsiveness (with a threshold of 10-15%), while peripheral parameters such as PPV or PVI fail to predict fluid responsiveness. The most convincing explanation is that SVV is absorbed by the high arterial compliance.

  *Pereira de Souza Neto et al. British Journal of Anaesthesia. 2011; 106(6): 856-64*
PlethVariability Index (PVI)

But...About Cardiovascular Status of the patient:

• Requires regular (sinusal) HR (atrial fibrillation, frequent PVC)
• A failing right or left heart can be preload independent

• Not if severe valvular disease
SUMMARY

Goal Directed Therapy: Volume Expansion (VE) \(\rightarrow \Delta \text{CO}\)

Atrial filling optimal (not overstretched) means no release of ANP & no iatrogenic destruction of glycocalyx

\[\Delta \text{CO} = \Delta \text{SV} \times \text{HR}\]

\((\rightarrow \Delta \text{Stroke Volume: High } \Delta = \text{VE} \rightarrow \uparrow \text{CO})\]

It gives information on where the patient is on Starling curve

\[\Delta \text{SV} \leftrightarrow \Delta \text{PI} = \text{PVI}\]

Optimal Fluid Status for PVI: 10 – 13%

In:
Adult patients
Positive pressure ventilation
No high PEEP
Sinusal HR
No severe valve disease
Not in low perfusion
PVI >13% = VE will increase CO
VE or NO VE depending on clinical context

Hard to be more simple,
less invasive (and cheaper)
Pulsus Paradoxus

• Clinical occurrence of PP

  Low intrathoracic pressure during spontaneous inspiration

  Cardiac tamponade
  Chronic obstructive airway disease
  Pulmonary embolism
  Severe asthma, etc.
The Ability of Pleth Variability Index to Predict the Hemodynamic Effects of Positive End-Expiratory Pressure in Mechanically Ventilated Patients Under General Anesthesia

Olivier Desebbe, MD,* Cécile Boucau, MD,* Fadi Farhat, MD, PhD;† Olivier Bastien, MD, PhD,* Jean-Jacques Lehot, MD, PhD,* and Maxime Cannesson, MD, PhD*
Clinical Applications of Pulse Pressure Variability

- Colorectal (Haifang et al, Chin Med J 2002)
- Pheo (Mallat et al, C J Anesth 2003)
- CABG (Cannesson et al, Anesth Analg 2008)
- PO CABG (Rex et al, B J Anaesth 2004)
- Hepatectomy (Solus et al, B J Anaesth 2006)
- High-risk (Lopes et al, Crit Care 2007)
Fifteen hundred simultaneous measurements of blood volume and CVP in a heterogenous cohort of 188 ICU patients demonstrating no association between these two variables ($r = 0.27$).


**Table 3**

<table>
<thead>
<tr>
<th>Prediction of change in stroke volume index with receiver operating characteristic analysis</th>
<th>Area under the curve</th>
<th>P-value</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVP induction of anesthesia</td>
<td>0.54</td>
<td>0.69</td>
<td>0.32–0.76</td>
</tr>
<tr>
<td>PCWP induction of anesthesia</td>
<td>0.54</td>
<td>0.72</td>
<td>0.31–0.77</td>
</tr>
<tr>
<td>GEDVI induction of anesthesia</td>
<td>0.60</td>
<td>0.34</td>
<td>0.38–0.62</td>
</tr>
<tr>
<td>SVV induction of anesthesia</td>
<td>0.69</td>
<td>0.10</td>
<td>0.47–0.90</td>
</tr>
<tr>
<td>PPV induction of anesthesia</td>
<td>0.67</td>
<td>0.14</td>
<td>0.43–0.91</td>
</tr>
<tr>
<td>Delta CVP</td>
<td>0.65</td>
<td>0.13</td>
<td>0.45–0.87</td>
</tr>
<tr>
<td>Delta PCWP</td>
<td>0.57</td>
<td>0.55</td>
<td>0.35–0.79</td>
</tr>
<tr>
<td>Delta GEDVI</td>
<td>0.76</td>
<td>0.01</td>
<td>0.61–0.91</td>
</tr>
<tr>
<td>Delta SVV</td>
<td>0.85</td>
<td>0.01</td>
<td>0.69–0.98</td>
</tr>
<tr>
<td>Delta PPV</td>
<td>0.82</td>
<td>0.02</td>
<td>0.63–0.96</td>
</tr>
</tbody>
</table>

CVP, central venous pressure; GEDVI, global end-diastolic volume index; PCWP, pulmonary capillary wedge pressure; PPV, pulse pressure variation; SVV, stroke volume variation.
CNAP ≈ Invasive Arterial Pressure

- Blood volume in a finger is kept constant by applying corresponding pressure.

- The constantly changing external pressure needed to keep the volume constant coresponds to the arterial pressure.
The Ability of Pulse Pressure Variations Obtained with CNAP™ Device to Predict Fluid Responsiveness in the Operating Room

Matthieu Biais, MD,*† Laurent Stecken, MD,* Laetitia Ottolenghi, MD,* Stéphanie Rouillet, MD,* Alice Quinart, MD,* Françoise Masson, MD,* and François Sztark, MD, PhD*†

BACKGROUND: Respiratory-induced pulse pressure variations obtained with an arterial line (ΔPP_{ART}) indicate fluid responsiveness in mechanically ventilated patients. The Infinity® CNAP™ SmartPod® (Dräger Medical AG & Co. KG, Lübeck, Germany) provides noninvasive continuous beat-to-beat arterial blood pressure measurements and a near real-time pressure waveform. We hypothesized that respiratory-induced pulse pressure variations obtained with the CNAP system (ΔPP_{CNAP}) predict fluid responsiveness as well as ΔPP_{ART} predicts fluid responsiveness in mechanically ventilated patients during general anesthesia.

METHODS: Thirty-five patients undergoing vascular surgery were studied after induction of general anesthesia. Stroke volume (SV) measured with the Vigileo™/FloTrac™ (Edwards Lifesciences, Irvine, CA), ΔPP_{ART}, and ΔPP_{CNAP} were recorded before and after intravascular volume expansion (VE) (500 ml of 6% hydroxyethyl starch 130/0.4). Subjects were defined as responders if SV increased by ≥15% after VE.

RESULTS: Twenty patients responded to VE and 15 did not. The correlation coefficient between ΔPP ART and ΔPP CNAP before VE was r = 0.90 (95% confidence interval [CI] = 0.84–0.96; P < 0.0001). Before VE, ΔPP ART and ΔPP CNAP were significantly higher in responders than in nonresponders (P < 0.0001). The values of ΔPP ART and ΔPP CNAP before VE were significantly correlated with the percent increase in SV induced by VE (respectively, r² = 0.50; P < 0.0001 and r² = 0.57; P < 0.0001). Before VE, a ΔPP ART >10% discriminated between responders and nonresponders with a sensitivity of 90% (95% CI = 69%–99%) and a specificity of 87% (95% CI = 60%–98%). The area under the receiver operating characteristic (ROC) curve was 0.957 ± 0.035 for ΔPP ART. Before VE, a ΔPP CNAP >11% discriminated between responders and nonresponders with a sensitivity of 85% (95% CI = 62%–97%) and a specificity of 100% (95% CI = 78%–100%). The area under the ROC curve for ΔPP ART and ΔPP CNAP was 0.942 ± 0.040. There was no significant difference between the area under the ROC curve for ΔPP ART and ΔPP CNAP.

CONCLUSIONS: A value of ΔPP CNAP >11% has a sensitivity of at least 62% in predicting preload-dependent responders to VE in mechanically ventilated patients during general anesthesia. (Anesth Analg 2011;113:523–B)

Figure 1. Box plots (median values, interquartile range) and individual values of pulse pressure variations obtained with the arterial line (ΔPP ART) and pulse pressure variations obtained with the CNAP device (ΔPP CNAP) before intravascular volume expansion in responders (Rs) and in nonresponders (NRs).

Figure 3. Receiver operating characteristic curves showing the ability of respiratory-induced pulse pressure variations obtained with an arterial line (ΔPP ART) and respiratory-induced pulse pressure variations obtained with the CNAP system (ΔPP CNAP) to predict fluid responsiveness.