Perioperative volume management
– can we do better?

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Disclosure

The speaker cooperates with the following companies:

Drager-Siemens (RSVT personal patent)*

iMDsoft

Pulsion*
The identification and prevention of occult hypovolemia and impaired cardiac function in order to increase tissue perfusion is crucial for the individual high-risk surgical patient.

On the other hand, fluid overload and unjustified use of vasopressors and/or inotropes may have detrimental effects.

This is further complicated by the dynamic pace of physiological events and insults during anesthesia and surgery.
Can hemodynamic monitoring improve perioperative care?

1. The wide variability of patient populations, co-morbidities, surgical procedures and their associated morbidity and mortality.

2. Incomplete understanding of what exactly makes the patient better (or worse), e.g., restrictive vs. liberal fluid management.

3. Choosing the parameters that are most important to monitor.

4. Defining the values that we want to achieve (how much? for how long?).
Can hemodynamic monitoring improve perioperative care?

5. The type of monitoring-guided interventions (fluids, inotropes, etc.) and their timing (pre-, intra-, post-op).

6. Factors like invasiveness, cost, time-consumption, patient tolerance, possible complications.


8. Contradictory data in the medical literature.


10. Influence of industry.
During anesthesia and throughout the perioperative period we employ a goal-directed approach to keep vital signs within normal limits.

There are however no accepted values even for the ‘normal’ limits of these basic parameters, which have been shown to vary according to the type of patient, stage of procedure and the local or personal approach.


Acceptable ranges for vital signs during general anesthesia.

van Oostrom JH, Gravenstein C, Gravenstein JS.

The definition of specific physiological end-points is not easy.
No monitoring device can improve patient-centered outcomes unless it is coupled to a treatment that improves outcome.
Fluid management of patients undergoing abdominal surgery – more questions than answers

Boldt J. Eur J Anaesthesiol 2006; 23: 631-40
Fluid overload, defined as a gain greater than 10% of the preoperative weight, occurred in 40% of patients. The degree of weight gain was significantly associated with vasopressor dependence, colloid administration, and mortality. The morbidity of fluid overload can be significant and warrants a fresh look at the methods of intraoperative fluid resuscitation.

Postoperative fluid overload: not a benign problem
Effects of intravenous fluid restriction on postoperative complications: comparison of two perioperative fluid regimens: a randomized assessor-blinded multicenter trial.


Conclusion: The restricted perioperative intravenous fluid regimen aiming at unchanged body weight reduces complications after elective colorectal resection.
Conclusions: In patients undergoing elective intra-abdominal surgery, intraoperative use of restrictive fluid management may be advantageous because it reduces postoperative morbidity and shortens hospital stay.
Positive salt and water balance sufficient to cause a 3 kg weight gain after surgery delays return of GI function and prolongs hospital stay in patients undergoing elective colonic resection.

The development of edema was associated with a delay in tolerating solid food and opening bowels, a prolonged hospital stay and more postoperative complications. Age and reduced ability to excrete administered fluid load are significant etiological factors.
“We have to re-examine whether we have indeed started to underestimate the effects of fluid overload even in patients undergoing medium-risk surgery…

…..IV fluids, the most commonly used drug in the hospital, are a double-edged sword.”
Fluid management varied, with colloid (hydroxyethyl starch or albumin) used in 30% of cases and a mean intravenous crystalloid replacement of 9.7±4.7 l.

This volume of infusion is far in excess of what is necessary for maintenance of either blood pressure or urine output. In addition, it has a serious negative impact on the hematocrit, as well as promoting edema of the orbs and optic nerves. (C. Philip Larson)
Liberal or restrictive fluid administration in fast-track colonic surgery: a randomized, double-blind study

K. Holte¹*, N. B. Foss², J. Andersen¹, L. Valentiner¹, C. Lund², P. Bie³ and H. Kehlet⁴

<table>
<thead>
<tr>
<th>Table 1 Protocol of fluid administration and patient management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1</strong> (restrictive fluid)</td>
</tr>
<tr>
<td><strong>Bowel preparation</strong></td>
</tr>
<tr>
<td>Not used</td>
</tr>
<tr>
<td><strong>Before operation</strong></td>
</tr>
<tr>
<td>400+400 ml glucose drink the evening before and 2 h before surgery</td>
</tr>
<tr>
<td><strong>Preload (at placement of epidural)</strong></td>
</tr>
<tr>
<td>None</td>
</tr>
<tr>
<td><strong>Fluid protocol during surgery</strong></td>
</tr>
<tr>
<td>7 ml kg⁻¹ h⁻¹ RL first hour</td>
</tr>
<tr>
<td>5 ml kg⁻¹ h⁻¹ RL subsequent hours</td>
</tr>
<tr>
<td><strong>After operation (PACU) on the day of surgery</strong></td>
</tr>
</tbody>
</table>
| No i.v. fluids                                                | Two protein drinks+600 ml of water=
|                                                               | litre oral intake. |
|                                                               | No i.v. fluids on the ward without specific indication (hypotension, systolic pressure<90 mm Hg on two repeated measurements) |
| **Postoperative day 1**                                       | **Postoperative day 2** |
| Free solid food intake+four protein drinks                    | Removal of epidural catheter |
| Oral fluid intake aimed at 2–2.5 litre                        | Free solid food intake |
| Removal of bladder catheter                                   | Discharge according to departmental guidelines (sufficient pain relief on oral analgesics, sufficient oral intake, passage of flatus, and patient acceptance) |
### Patients

<table>
<thead>
<tr>
<th>Study</th>
<th>Condition</th>
<th>Definition of Responders</th>
<th>N</th>
<th>Challenge</th>
<th>Responders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preisman S (2005)</td>
<td>Cardiac surgery</td>
<td>&gt; 15% SV</td>
<td>18</td>
<td>250 mL colloids</td>
<td>32/70 VLS (46%)</td>
</tr>
<tr>
<td>Hofer CK (2005)</td>
<td>Cardiac surgery</td>
<td>&gt; 25% SVI</td>
<td>35</td>
<td>10 mL/kg (IBW) 6% HES</td>
<td>21 (60%)</td>
</tr>
<tr>
<td>Swensen CH (2006)</td>
<td>Abdominal surgery</td>
<td>Increase in CO</td>
<td>10</td>
<td>25 mL/kg of Ringer</td>
<td>4 (40%)</td>
</tr>
<tr>
<td>Tavernier B (1998)</td>
<td>Sepsis w. circulatory failure</td>
<td>&gt; 15% SVI</td>
<td>15</td>
<td>500-1000 mL HES</td>
<td>21/35 VLS (60%)</td>
</tr>
<tr>
<td>Michard F (2000)</td>
<td>Sepsis w. circulatory failure</td>
<td>&gt; 15% CI</td>
<td>40</td>
<td>500 mL HES</td>
<td>16 (40%)</td>
</tr>
<tr>
<td>Michard F (2003)</td>
<td>Septic shock</td>
<td>&gt; 15% SVI</td>
<td>27</td>
<td>500 mL HES</td>
<td>32/66 VLS (48%)</td>
</tr>
<tr>
<td>Feissel M (2005)</td>
<td>Septic shock</td>
<td>&gt; 15% CI</td>
<td>20</td>
<td>8 ml/kg HES</td>
<td>13/22 VLS (59%)</td>
</tr>
<tr>
<td>Monnet X (2005)</td>
<td>Critically ill w. circulatory failure</td>
<td>&gt; 15% increase in ABF (Doppler)</td>
<td>38</td>
<td>500 ml NS</td>
<td>20 (53%)</td>
</tr>
<tr>
<td>Vallee F (2005)</td>
<td>Critically ill w. circulatory failure</td>
<td>&gt; 10% increase in SVI</td>
<td>51</td>
<td>4 ml/kg colloid X 2</td>
<td>20 (39%)</td>
</tr>
<tr>
<td>Heenan S (2006)</td>
<td>Critically ill w. circulatory failure</td>
<td>&gt; 15% in CO</td>
<td>21</td>
<td>1 L Ringer or 500 mL HES</td>
<td>9 (43%)</td>
</tr>
<tr>
<td>Lafanechère A (2006)</td>
<td>Critically ill w. circulatory failure</td>
<td>&gt; 15% increase in ABF (Doppler)</td>
<td>22</td>
<td>PLR and 500 ml NS</td>
<td>10 (45%)</td>
</tr>
<tr>
<td>Osman D (2007)</td>
<td>Sepsis</td>
<td>&gt; 15% in CO</td>
<td>96</td>
<td>500 mL HES</td>
<td>65/150 VLS (43%)</td>
</tr>
</tbody>
</table>
Small hemodynamic effect of typical rapid volume infusions in critically ill patients

“The effects of a typical rapid volume infusion on hemodynamics and LV areas is surprisingly small.”
An IV infusion of 25 mL/kg of lactated Ringer’s solution was administered over 45 min to 10 patients during abdominal surgery.

CO decreased in 6 and increased in 4 patients.
Volume kinetic analysis suggested that in the responders 54% of the infused fluid resided in the central fluid space at the end of the infusion and 25% at the end of the study, compared with 25% and 3%, respectively, in non-responders.
Unlike approaches that adopt a specific clinical practice, like liberal or restrictive fluid regimen, goal-directed approaches employ various monitoring techniques and interventions in order to achieve specific end-points for selected parameters.

- **Preload parameters:** CVP, PAOP, GEDV
- **Fluid responsiveness:** SPV, PPV, SVV
- **Flow parameters:** CO, CI, SV
- **Oxygen delivery** ($DO_2$)
- **Mixed venous** ($SvO_2$) or central venous ($ScvO_2$) oxygen saturation
- **Lactate concentration**
- **pHi**
“Estimates of intravascular volume based on any given level of filling pressure do not reliably predict a patient’s response to fluid administration.”
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

CCM 2007 35:64-8

Occult hypoperfusion!

Fluid overload!
Global end-diastolic volume as an indicator of cardiac preload in patients with septic shock.

Pre-infusion GEDV index (mL/m²)

responders

non responders
Intrathoracic blood volume reflects more accurately the preload dependency of cardiac output than left/right-sided cardiac filling pressures.

Heart Transplantation
Goedje O, et al. CHEST 2000; 118:775–781

Lung transplantation

Liver transplantation
Intrathoracic blood volume reflects more accurately the preload dependency of cardiac output than left/right-sided cardiac filling pressures.

**Laparoscopic colonic surgery**

**Laparoscopic surgery**

**Cardiac surgery**

**Neurosurgery (sitting position)**
Functional hemodynamic parameters

Responder Non-responder

SPV  PPV  SVV

$PP_{max}$ $PP_{min}$

SVmax SVmin

Responder  Non-responder
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†
Respiratory variations in the plethysmographic signal

Before (A) and after (B) the administration of 1 L of crystalloids over 10 min.
Goal-directed fluid management based on pulse pressure variation monitoring during high-risk surgery: a pilot randomized controlled trial

Marcel R Lopes¹, Marcos A Oliveira¹, Vanessa Oliveira S Pereira¹, Ivaneide Paula B Lemos¹, Jose Otavio C Auler Jr² and Frédéric Michard³

Methods Thirty-three patients undergoing high-risk surgery were randomized either to a control group (group C, n = 16) or to an intervention group (group I, n = 17). In group I, ΔPP was continuously monitored during surgery by a multiparameter bedside monitor and minimized to 10% or less by volume loading.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiologic status at end of surgery</td>
<td></td>
</tr>
<tr>
<td>Heart rate (l/min)</td>
<td>86 ± 19</td>
</tr>
<tr>
<td>Mean arterial pressure (mmHg)</td>
<td>68 ± 20</td>
</tr>
<tr>
<td>SpO₂ (percentage)</td>
<td>97 ± 3</td>
</tr>
<tr>
<td>ΔPP (percentage)</td>
<td></td>
</tr>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>9.8 ± 1.4</td>
</tr>
<tr>
<td>Fluid administered</td>
<td></td>
</tr>
<tr>
<td>Volume of crystalloid infused (ml)</td>
<td>1,563 ± 602</td>
</tr>
<tr>
<td>Volume of colloid infused (ml)</td>
<td>0</td>
</tr>
<tr>
<td>Volume of red blood cells infused (ml)</td>
<td>131 ± 268</td>
</tr>
<tr>
<td>Number of patients who received red blood cells</td>
<td>4</td>
</tr>
<tr>
<td>Volume of FFP infused (ml)</td>
<td>0</td>
</tr>
<tr>
<td>Number of patients who received FFP</td>
<td>0</td>
</tr>
<tr>
<td>Total volume infused (ml)</td>
<td>1,694 ± 705</td>
</tr>
<tr>
<td>Total volume infused (ml/kg per hour)</td>
<td>7 ± 2</td>
</tr>
</tbody>
</table>
The number of postoperative complications, the duration of mechanical ventilation, the LOS in the ICU, and the LOS in hospital (7 versus 17 days, $P<0.01$) were lower in group I than in group C.

Conclusion: Monitoring and minimizing $\Delta PP$ by volume loading during high-risk surgery improves postoperative outcome and decreases the length of stay in hospital.

<table>
<thead>
<tr>
<th>Physiologic status at start of surgery</th>
<th>Group I</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (/min)</td>
<td>66 ± 9</td>
<td>77 ± 17</td>
</tr>
<tr>
<td>Mean arterial pressure (mmHg)</td>
<td>96 ± 16</td>
<td>90 ± 18</td>
</tr>
<tr>
<td>SpO$_2$ (percentage)</td>
<td>97 ± 3</td>
<td>97 ± 3</td>
</tr>
<tr>
<td>$\Delta PP$ (percentage)</td>
<td></td>
<td>22 ± 7</td>
</tr>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>11.3 ± 2.0</td>
<td>11.9 ± 2.5</td>
</tr>
</tbody>
</table>
Online Monitoring of Pulse Pressure Variation to Guide Fluid Therapy After Cardiac Surgery

High-risk surgical patients were randomized to achieve standard clinical values as therapeutic goals using either a CVP or a pulmonary artery catheter (PAC).

In a third protocol group ‘supra-normal’ levels of CI (> 4.5 L/min/m²) and DO₂ (> 600 ml/min/m²) were achieved with fluid loading, packed red blood cells, inotropes and vasodilators.

Results: Mortality was 33% and 23% in the PAC and CVP control groups, respectively, and only 4% in the protocol group, which also had a significant reduction of major complications and of ICU length of stay.
A Randomized, Controlled Trial of the Use of Pulmonary-Artery Catheters in High-Risk Surgical Patients

James Dean Sandham, M.D., Russell Douglas Hull, M.B., B.S., Rollin Frederick Brant, Ph.D., Linda Knox, R.N., Graham Frederick Pineo, M.D., Christopher J. Doig, M.D., Denny P. Laporta, M.D., Sidney Viner, M.D., Louise Passerini, M.D., Hugh Devitt, M.D., Ann Kirby, M.D., Michael Jacka, M.D., for the Canadian Critical Care Clinical Trials Group

There is no benefit to therapy directed by PAC (DO₂ of 550-600 ml/min/m², CI 3.5-4.5 L/min/m², mean arterial pressure of 70 mmHg, and PAOP of 18 mmHg) over standard care in elderly, high-risk surgical patients.
In severely traumatized patients, ‘supra-normal’ resuscitation was associated with more fluids, decreased intestinal perfusion, increased incidence of intra-abdominal hypertension and abdominal compartment syndrome, multiple organ failure, and death.
ICU protocol may affect the outcome of non-elective abdominal aortic aneurysm repair.


Department of Surgery, Guy's Hospital, London, U.K.

145 patients who underwent emergency (46) or urgent (99) repair of an abdominal aortic aneurysm by the same surgeon in 2 different hospitals.

<table>
<thead>
<tr>
<th></th>
<th>Hospital #1*</th>
<th>Hospital #2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA cath</td>
<td>96%</td>
<td>18%</td>
</tr>
<tr>
<td>Crystalloids (mls)</td>
<td>2990</td>
<td>2300</td>
</tr>
<tr>
<td>Colloids (mls)</td>
<td>4775</td>
<td>1500</td>
</tr>
<tr>
<td>Renal failure</td>
<td>28%</td>
<td>8%</td>
</tr>
<tr>
<td>Mortality</td>
<td><strong>28%</strong></td>
<td>9%</td>
</tr>
</tbody>
</table>
A prospective randomized trial of preoperative "optimization" of cardiac function in patients undergoing elective peripheral vascular surgery
Ziegler DW et al, Surgery 1997; 122: 584–92

Routine pulmonary artery catheterization does not reduce morbidity and mortality of elective vascular surgery: results of a prospective, randomized trial

Effectiveness of pulmonary artery catheters in aortic surgery: a randomized trial

The preoperative insertion of a PAC in order to optimize PAOP, CI and/or SvO₂ does not improve patient outcome.

Overall mortality in all these studies was less than 10%!
Perioperative Goal-Directed Therapy using esophageal Doppler ultrasonography

Achieving the goal.
*Boyd O, Bennett ED. Critical Care Medicine 1999; 27: 2298-9*


Five studies (420 patients) undergoing major abdominal surgery who were randomly allocated to receive either IV fluid guided by esophageal Doppler monitor or according to conventional parameters.

Pooled analysis showed a reduced hospital stay, fewer complications and ICU admissions, less requirement for inotropes and faster return of normal GI function in the intervention group.
In 2 studies (130 patients) the intraoperative use of esophageal Doppler or CVP monitoring led to significant increases in fluid volumes infused and reductions in length of hospital stay.

Although no serious complications were directly attributable to the interventions, their effects on other important, patient-centered, longer-term outcomes are uncertain. Adverse effects on fatality cannot be excluded.

The lack of randomized studies of adequate quality addressing this important question is disappointing. More research is needed.
In view of the accumulation of evidence showing that increasing DO$_2$ in high-risk surgical patients may reduce morbidity and save lives, it may be considered unethical not to use goal-directed perioperative therapy once patient identification and the methods to be used in treating them are refined.
Goal-directed fluid management reduces vasopressor and catecholamine use in cardiac surgery patients

In the goal-directed therapy (GDT) group hemodynamic management was guided by an algorithm based on GEDVI. Hemodynamic goals were: GEDVI above 640 ml/m², cardiac index above 2.5 l/min/m², and mean arterial pressure above 70 mmHg. The control group was treated at the discretion of the attending physician based on central venous pressure, mean arterial pressure, and clinical evaluation.
Goal-directed fluid management reduces vasopressor and catecholamine use in cardiac surgery patients

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**Flowchart Diagram**

- **GEDVI >640**
  - yes: CI >2.5
  - no: EVLWI >10
    - yes: GEDVI >800
      - yes: MAP >70
        - yes: HR >80
          - yes: HR <110
            - yes: OK
          - no: EVLWI >10
            - yes: give volume until GEDVI >800
            - no: GEDVI >800
              - yes: give volume until GEDVI >800
              - no: EVLWI >10
                - yes: give volume until GEDVI >800
                - no: EVLWI >10
                  - yes: give volume until GEDVI >800
                  - no: sedation, Hb elevation, pharmacotherapy

- In case of EVLWI >12: care for signs of pulmonary edema and give diuretics if necessary

- give catecholamines until CI >2.5
- give vasopressors until MAP >70
- perform pacing, give chronotropes
Total cumulative amount of vasopressor therapy during surgery and ICU stay.

* p < 0.01
Blood lactate levels before surgery, at the end of surgery, and during ICU stay

Goepfert et al, ICM 2007
The results of this study suggest that algorithm-driven, perioperative hemodynamic management based on early optimization of preload and cardiac output using transpulmonary thermodilution leads to an improved treatment of patients undergoing cardiac surgery.
STD and continuous ScvO₂ monitoring allowed an early recognition of hypovolemia and myocardial depression, thereby influencing fluid and inotrope / vasopressor therapy and decreasing hospital length of stay after OPCAB, as compared with conventionally monitored patients.

Pediatric cardiac surgery

Pediatric liver transplantation

Cardiac surgery in infants and children

Routine clinical assessment of parameters of cardiac performance agreed poorly with invasive determinations of these indices (underestimation of CO and overestimation of SVR and preload).
Perioperative pulmonary edema


Mild, subclinical, pulmonary oedema is relatively common after major vascular surgery, mainly caused by increased pulmonary capillary permeability in the absence of overt heart failure.


Baseline pulmonary vascular permeability and EVLW were above normal in 60 and 30% of the patients undergoing cardiac and major vascular surgery.


EVLW measurement predicts the pulmonary complications induced by esophagectomy with extended lymph node dissection.
EVLW after pneumonectomy and one-lung ventilation in sheep

Pneumonectomy and injurious ventilation of the left lung, increased EVLW values which compared acceptably with postmortem gravimetry.

Ventilator-induced lung injury seems to be a crucial mechanism of pulmonary edema after pneumonectomy.
Volumetric monitoring with the PiCCO helped clinical decisions during HHH therapy by maintaining a hypertensive and hypervolemic state while avoiding cardiopulmonary complications such as heart failure and pulmonary edema, and avoiding the need for mechanical ventilation.
Pulmonary edema in a 63 years old patient during re-total hip replacement.
In recovery - BP 63/40, HR 137 b/min  
Following dopamine and adrenaline BP 96/63

**PiCCO parameters**

<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>Low CO</td>
</tr>
<tr>
<td>ITBVI</td>
<td>779 ml/m²</td>
<td>Moderately low preload</td>
</tr>
<tr>
<td>SVV</td>
<td>22 %</td>
<td>Volume responsiveness</td>
</tr>
<tr>
<td>EVLW</td>
<td>23 ml/kg</td>
<td>Pulmonary edema</td>
</tr>
</tbody>
</table>

**Normal range**

- CI: 3.5 - 5.0
- ITBVI: 850-1000
- SVV: <10%
- EVLW: 3-7

*Interpretation*:
- Low CO
- Moderately low preload
- Volume responsiveness
- Pulmonary edema
The PiCCO values over the next 2 days

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI (l/m²)</td>
<td>3.75</td>
</tr>
<tr>
<td>ITBVI (ml/m²)</td>
<td>1444 !!!</td>
</tr>
<tr>
<td>SVV (%)</td>
<td>15</td>
</tr>
<tr>
<td>EVLW (ml/kg)</td>
<td>15</td>
</tr>
</tbody>
</table>
Perioperative hemodynamic monitoring
– don`t get off track

When do I use advanced hemodynamic monitoring during anesthesia?

• CHF + major surgery
• Sepsis
• ARDS, MOF
• Perforated bowel / anastomtic leak
• Pulmonary edema
• Therapeutic conflicts
Perioperative hemodynamic monitoring
– don’t get off track

How do I use advanced hemodynamic monitoring?

CVP, PCWP – no.

ScvO₂ – yes (beware in sepsis; when low seek more information).

CO – yes (to follow effects of therapeutic interventions and to detect excessive deviations but not for maximalization; ideally with ScvO₂).

GEDV – yes.

PPV/SVV – yes (but as part of the ‘general picture’).

EVLW – major importance in the critically ill.
Thank You!