WHAT IS OPTIMAL PERFUSION?
A REVIEW

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Everyone who earnestly practices perfusion is acting with the full belief that what they are doing is in the best interest of their patients.

„Perfusion can never be normal, only adequate!“
"Flow rate must equal the basal cardiac output to ensure a wide margin of safety in the metabolic support of tissues."
Perfusion Flow

- Flow affects blood trauma, embolic load, collateral flow, surgical field.
- Influence of temperature and haemodilution
- Flow and pressure are inter-related & dynamic
- ? Pulsatile flow

What is optimal perfusion?
"The question of arterial pressure and its relationship to optimal perfusion flow rates is of major importance, but the prevailing opinions are diverse and contradictory.

The overwhelming evidence appears to indicate that there is no definite prescribed flow rate, but a range of physiologic parameters within which one can perfuse with a relative margin of safety, dependent on the prevailing circumstances."
CARDIAC OUTPUT

- Changes based on metabolic needs
- Usually in the range of 2.8 to 3.0 L/min/m²
  May increase up to 15 L/min/m²
- CO with arterial oxygen content, determines the oxygen delivery ($DO_2$)
- Guaranty oxygen need ($VO_2$)
- Pulsatile flow

CPB FLOW

- Adjusted by the perfusionist based on temperature and blood pressure
- 2.0 to 3.0 L/min/m²
- Adequacy of the pump flow controlled with $SvO_2$ monitoring
- $Qb$ with arterial oxygen content, determines the oxygen delivery ($DO_2$)
- Should guaranty oxygen need ($VO_2$)
Is Perfusion optimal when....?

- Flow is 2.4 LPM/m²
- MAP ≈ 60 mmHg
- ABG = normal
- SvO₂ > 75%
“Optimal Perfusion should guarantee an adequate oxygen supply by maintaining oxygen delivery $DO_2$ at the tissue level!”

Optimal Versus Suboptimal Perfusion During Cardiopulmonary Bypass and the Inflammatory Response
F. De Somer, SEMIN CARDIOTHORAC VASC ANESTH 2009
Oxygen Transport

The blood oxygen content based on:

- hemoglobin content, and
- dissolved $O_2$

Described by the equation:

$$CaO_2 = (1.34 \times Hb \times SaO2) + (0.003 \times PaO2)$$
Oxygen Delivery

- \( \text{O}_2 \) delivery = DO\(_2\) = CO \times \text{CaO}_2 \times 10

- Usually = 520-570 ml/min/m\(^2\)

- “dysoxia threshold” \( \leq 270 \) ml/min/m\(^2\)
Oxygen Delivery:

If the **Blood-Flow** is constantly

**DO₂** is determinant by

**Haemoglobin Content**
Oxygen Consumption $\text{VO}_2$

Depends of:

- Cardiac output
- Difference in oxygen content b/w arterial and venous blood

$$\text{VO}_2 = \text{CO} \times 1.34 \times \text{Hb} \times (\text{SaO}_2 - \text{SvO}_2)_{10}$$
Influencing Factors of Oxygen Consumption = $\text{VO}_2$

Temperature:

$\text{VO}_2$ decrease approx. 7% per 1°Celsius.

Anesthesia:

- 37°C: 4 mL/kg/min
- 37°C + Anesthesia: 2-3 mL/kg/min
- 28°C + Anesthesia: 1-2 mL/kg/min
O₂ER (Oxygen Extraction Ratio) Normal: 24-28%

O₂ER = VO₂/DO₂

Increase:
- Hypovolemia
- Hypoperfusion
- Hyperthermia
- Anemia
- Hypoxia

Decrease:
- Decreased Metabolic Rate
- Alkalosis
- Anesthesia
- Hypothermia
Tissue Oxygenation

✓ To keep tissues aerobic metabolism we need oxygen.

✓ Allows the conversion of glucose to ATP

✓ We get 36 moles ATP per mole glucose
Tissue Oxygenation

- Less oxygen = anaerobic metabolism
  “dysoxia threshold” ≤ 270 ml/min/m²

- Only 2 moles ATP per mole glucose

- Production of lactate
The Role of Hematocrit Value

“Patients experiencing a single HCT value of 19% or less during CPB had more than twice the mortality as patients with a nadir HCT value of 25%!”

DeFoe 2001, Multicenter study of 6980 patients undergoing isolated CABG surgery.

“Hematocrit below 21% is associated with increase of renal failure, stroke and morbidity and mortality.”
# The Influence of Hematocrit

## Table 5. Lowest Hematocrit on CPB and Outcomes: Data-Based Investigations

<table>
<thead>
<tr>
<th>Author</th>
<th>No of patients</th>
<th>Outcome variables</th>
<th>Critical Hct values</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeFoe et al., 2001</td>
<td>6980</td>
<td>In-hospital mortality</td>
<td>23%</td>
<td>Lowest Hct associated with increased in-hospital mortality, need for IABP, and return to CPB</td>
</tr>
<tr>
<td>Habib et al., 2003</td>
<td>5000</td>
<td>In-hospital mortality; morbidity</td>
<td>22%</td>
<td>Lowest Hct associated with increased mortality, morbidity, and resource utilization</td>
</tr>
<tr>
<td>Fang et al., 1997</td>
<td>2738</td>
<td>In-hospital mortality; long-term survival</td>
<td>14% all patients</td>
<td>Lowest Hct associated with increased mortality</td>
</tr>
<tr>
<td>Karkouti et al., 2005</td>
<td>9080</td>
<td>ARF requiring dialysis</td>
<td>&lt;21% or &gt;25%</td>
<td>Hct values &lt;21% or &gt;25% associated with increased risk of ARF</td>
</tr>
<tr>
<td>Habib et al., 2005</td>
<td>1760</td>
<td>Change in serum creatinine; ARF</td>
<td>24%</td>
<td>Lowest Hct on CPB associated with increased risk of creatinine rise and ARF</td>
</tr>
<tr>
<td>Swaminathan et al., 2003</td>
<td>1404</td>
<td>Change in serum creatinine; ARF</td>
<td>None identified</td>
<td>Lowest Hct associated with creatinine rise</td>
</tr>
<tr>
<td>Ranucci et al., 2006</td>
<td>1766</td>
<td>In-hospital mortality; morbidity</td>
<td>23%</td>
<td>Lowest Hct associated with cardiac low output syndrome and ARF</td>
</tr>
<tr>
<td>Karkouti et al., 2005</td>
<td>10,949</td>
<td>Stroke</td>
<td>None identified</td>
<td>Lowest Hct associated with increased risk of stroke</td>
</tr>
</tbody>
</table>

CPB = cardiopulmonary bypass; Hct = hematocrit; IABP = intraaortic balloon pump; ARF = acute renal failure.

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**Optimal Perfusion During Cardiopulmonary Bypass: An Evidence-Based Approach**

Glenn S. Murphy, MD 2008 ;ANESTHESIA & ANALGESIA
"Patients with a low DO$_2$ have a high risk of RR-ARF regardless of their HCT value; conversely, if the DO$_2$ is maintained above the critical threshold,(270 mL/min/m$^2$) the RR-ARF risk is low, again regardless of the HCT."

Fig 3. Acute renal failure rate in the study population according to the presence of the two risk factors (low hematocrit and low oxygen delivery).

„To guarantee sufficient oxygen supply for peripheral tissue a careful coupling of pump-flow and arterial oxygen content is mandatory. Keep the blood-flow high enough to hold DO₂ above the critical level (> 270ml/min/m²)“
Hello Houston....
Mhm....
We have problems concerning SvO₂ levels!
Monitorsing of $S_vO_2$

Inline – Monitoring (most common)

- Venous Saturation – $S_vO_2$
- Venous partial oxygen Tension – $P_vO_2$

- Did not guarantee optimal tissue oxygenation
- Did not predict hyperlactatemia.

“Mixed venous saturation is a weak indicator especially for cerebral and splanchnic venous oxygen saturation.”

Is Perfusion adequate when....?

- Flow is 2,4 LPM/m²
- MAP ≈ 60 mmHg
- ABG = normal
- SvO2 > 75%
- Flow is coupled to HCT to keep DO₂ > 270ml/min/m²
• Regional Perfusion is still unknown

• We must be assured that DO$_2$ is adequate to the patient.

• We must monitor the metabolism also

  = Lactat

Several studies describe hyperlactatemia in up to 20% of all patients undergoing cardiac surgery with CPB indicating non-optimal perfusion.
“Hyperlactatemia during CPB is due mainly to a DO\textsubscript{2} inadequate to fulfill the metabolic needs of the patient, and this critical value is approximately 270 ml/min/m\textsuperscript{2}.

Therefore, every attempt should be applied to avoid HL during CPB, and the critical DO\textsubscript{2} value of 260 to 270 ml/minute per m\textsuperscript{2} should be considered whenever setting the pump flow and the maximum acceptable hemodilution degree.”

“Hyperlactatemia during cardiopulmonary bypass: determinants and impact on postoperative outcome” M. Ranucci, Critical Care 2006; Vol 10 No 6.
Anaerobic Metabolism During Cardiopulmonary Bypass: Predictive Value of Carbon Dioxide Derived Parameters

Marco Ranucci, MD, Giuseppe Isgrò, MD, Federica Romitti, MD, Sara Mele, MD, Bonizella Biagioli, MD, PhD, and Pierpaolo Giomarelli, MD, PhD

Annals of Thoracic Surgery; 2006

### Table 2. Univariate Analysis of Oxygen-Carbon Dioxide Derived Parameters and Other Intraoperative Variables at Arterial Lactate Determinations Below or Above the Threshold Value (3 mmol/L).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Arterial Lactates ≤ 3 mmol/L (n = 130)</th>
<th>Arterial Lactates &gt; 3 mmol/L (n = 37)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO₂ (mmHg)</td>
<td>225 ± 56</td>
<td>228 ± 44</td>
<td>0.7</td>
</tr>
<tr>
<td>SvO₂</td>
<td>0.78 ± 0.76</td>
<td>0.76 ± 0.8</td>
<td>0.15</td>
</tr>
<tr>
<td>VCO₂, i (mL · min⁻¹ · m⁻²)</td>
<td>51.4 ± 15.2</td>
<td>82.1 ± 38.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>DO₂, i/VCO₂, i</td>
<td>6.35 ± 1.7</td>
<td>4.14 ± 1.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>VCO₂, i/VO₂, i</td>
<td>0.77 ± 0.22</td>
<td>1.35 ± 0.68</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Aortic cross-clamp on</td>
<td>72%</td>
<td>46%</td>
<td>0.003</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>1.85 ± 0.2</td>
<td>1.62 ± 0.45</td>
<td>0.005</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>44.7 ± 36.3</td>
<td>68.9 ± 47.7</td>
<td>0.006</td>
</tr>
</tbody>
</table>

BSA = body surface area; CPB = cardiopulmonary bypass; DO₂, i/VCO₂, i = oxygen delivery indexed/carbon dioxide elimination indexed; PaO₂ = arterial oxygen tension; SvO₂ = mixed venous oxygen saturation; VCO₂, i = carbon dioxide elimination indexed; VCO₂, i/VO₂, i = respiratory quotient.
“Carbon dioxide derived parameters are representative of hyperlactatemia during CPB, as a result of the carbon dioxide produced under anaerobic conditions through the buffering of protons by the bicarbonate system.

The carbon dioxide elimination rate measured at the exhaled site of the oxygenator may be used for an indirect assessment of the metabolic state of the patient.”

Predictor of Hyperlactatemia:
“If the ratio between oxygen delivery and carbon dioxide production is lower than 5.”

Anaerobic metabolism during cardiopulmonary bypass: predictive value of carbon dioxide derived parameters.
Correlation between Oxygen Delivery $\text{DO}_2$ and $\text{CO}_2$ production
We have to be aware:
The interpretation of lactate measurement requires caution.

• The Lactate concentration depends on balance between production and clearance.

• Very Rapid production of Lactate but the Clearance depends on the metabolic elimination and is prolonged.

Monitoring of Carbon Dioxide derived parameters together with Oxygen delivery can be a considerable aid. To optimize the pump-flow and the arterial oxygen content.
Is Perfusion optimal when...?

- Flow is 2.4l / min / m²
- MAP is 60mmHg
- ABG is normal
- SvO₂ is > 75%
- The flow is coupled to the Hct to guarantee a
  \[\text{DO}_2 > 270 \text{ ml / min / m}^2\]
- The flow ensures no lactate formation according to the \[\text{DO}_2 / \text{VCO}_2\] ratio
Tissue Monitoring

Brain
Liver
Kidney
Bowel
Muscle
Vascular
Tissue Monitoring
48. If Perfusion ain’t happy, ain’t nobody happy!

“Heart Surgeon`s Little Instruction Book”
Heart-Lung-Bypass: principles and techniques of extracorporeal circulation” by Galleti and Brecher 1962


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Glenn S. Murphy, MD 2008 ;ANESTHESIA & ANALGESIA

The relationship between mixed venous and regional venous oxygen saturation during cardiopulmonary bypass.

Combination of venoarterial PCO2 difference with arteriovenous O2 content difference to detect anaerobic metabolism in patients.

Oxygen delivery during cardiopulmonary bypass and acute renal failure after coronary operations.

Acute renal injury and lowest hematocrit during cardiopulmonary bypass: Not only a matter of cellular hypoxemia.

Hyperlactatemia during cardiopulmonary bypass: determinants and impact on postoperative outcome.

Anaerobic metabolism during cardiopulmonary bypass: predictive value of carbon dioxide derived parameters.

Optimal Versus Suboptimal Perfusion During Cardiopulmonary Bypass and the Inflammatory Response
F. De Somer, Seminars in Cardiothoracic and Vascular Anesthesia, 2009;13 :2;113-117

What Is Optimal Flow and How to Validate This F.ilip De Somer, JECT. 2007;39:278–280

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