Pump Flow
- that’s what the Perfusionist controls, right?

Well:
• Does the pump deliver what we expect?

Is pump flow the same as CO?
What is the "effective Flow"?
• Loss from shunts in circuit
• Shunts in patient

does the pump deliver what we expect?

Roller pump
Estimated flow from RPM
Actual pumpflow depends upon:

- RPM
- Raceway
- Stroke volume
- Occlusion setting
- Tube
- Fluid (viscosity)
- Pre- and afterload
- Correct calibration

Occlusion settings

**Hard:**
- Descent rate < 0-1 cm/min
  - 5 RPM against occlusion \( \Rightarrow \) > 350 mmHg

**Medium:**
- Descent rate 2-3 cm/min
  - 5 RPM against occlusion \( \Rightarrow \) 250 - 350 mmHg

**Light:**
- Descent rate 4-10 cm/min
  - 5 RPM against occlusion \( \Rightarrow \) 200 - 250 mmHg
**Preload - Afterload**

Low preload causes:
- VAVD
- Constriction (3/8”)
- Kink of pump inlet (Mayo report: down to 45%)

High afterload causes:
- Oxygenator
- Tubing
- A-filter
- A-cannula
- Kinking

---

**Pre- and afterload**

- Flow vs Preload
- Flow vs Afterload

**Calibration of Pump**

- Measure flow
  - with realistic pre- and afterload
- Dependent of tubing
- Standardized occlusion
Flow at roller pump

Pulsation?

Table 6: Clinical Studies of the Effects of Pulsatile and Nonpulsatile Perfusion on Outcomes

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Improved with pulsatile flow</th>
<th>No difference between pulsatile and nonpulsatile flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>Markis HM et al., 1993</td>
<td>Markis HM et al., 1993</td>
</tr>
<tr>
<td>Abnormal fluid</td>
<td>Taylor KM et al., 1992</td>
<td>Taylor KM et al., 1992</td>
</tr>
<tr>
<td>Renal injury</td>
<td>Teherani Y et al., 2003</td>
<td>Teherani Y et al., 2003</td>
</tr>
<tr>
<td>Splanchnic perfusion</td>
<td>Knafo M et al., 2003</td>
<td>Knafo M et al., 2003</td>
</tr>
<tr>
<td>Inflammatory mediator release</td>
<td>Gare JC et al., 1994</td>
<td>Gare JC et al., 1994</td>
</tr>
<tr>
<td>Release of endogenous vasoactive</td>
<td>Zuniga-Perez R et al., 2004</td>
<td>Zuniga-Perez R et al., 2004</td>
</tr>
<tr>
<td>factors (endothelins, plasminogen)</td>
<td>Carver K et al., 1994</td>
<td>Carver K et al., 1994</td>
</tr>
</tbody>
</table>

Effective FLOW

Loosing flow after pump:

- Internal shunts from oxygenator
- External shunts in circuit
- Shunts in/from patient
Shunts

- Oxygenator – CTR
- A-filter – CTR (sample)
- A-line – V-line
- Hemofilter
- Blood CPL

Calculated flow in blood at specified pressure difference in 1 m tubing
(Darcy-Weisbach Mod.1)

<table>
<thead>
<tr>
<th>Diam.</th>
<th>Diam.</th>
<th>Flow at 20 mmHg</th>
<th>Flow at 50 mmHg</th>
<th>Flow at 100 mmHg</th>
<th>Flow at 200 mmHg</th>
<th>Flow at 400 mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16</td>
<td>0.04</td>
<td>0.07</td>
<td>0.10</td>
<td>0.14</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Sample line</td>
<td>2.0</td>
<td>0.08</td>
<td>0.13</td>
<td>0.18</td>
<td>0.26</td>
<td>0.36</td>
</tr>
<tr>
<td>Sample line</td>
<td>2.5</td>
<td>0.14</td>
<td>0.22</td>
<td>0.31</td>
<td>0.44</td>
<td>0.63</td>
</tr>
<tr>
<td>1/8</td>
<td>3.18</td>
<td>0.25</td>
<td>0.40</td>
<td>0.57</td>
<td>0.80</td>
<td>1.1</td>
</tr>
<tr>
<td>3/16</td>
<td>4.76</td>
<td>0.70</td>
<td>1.1</td>
<td>1.6</td>
<td>2.2</td>
<td>3.1</td>
</tr>
<tr>
<td>1/4</td>
<td>6.35</td>
<td>1.4</td>
<td>2.3</td>
<td>3.2</td>
<td>4.5</td>
<td>6.4</td>
</tr>
<tr>
<td>5/16</td>
<td>2.81</td>
<td>2.5</td>
<td>4.0</td>
<td>5.6</td>
<td>7.9</td>
<td>11</td>
</tr>
<tr>
<td>3/8</td>
<td>9.53</td>
<td>4.0</td>
<td>6.3</td>
<td>8.9</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>1/2</td>
<td>12.7</td>
<td>8.1</td>
<td>13</td>
<td>18</td>
<td>26</td>
<td>36</td>
</tr>
</tbody>
</table>

Sample line

- "Stolen" blood flow: effect of an open arterial filter purge line in a simulated neonatal CPB model.
- Wang S, Department of Pediatrics, Penn State College Medicine, Penn State Children’s Hospital, Hershey, Pennsylvania 17033-0850, USA.

Sample line open. Pressure 180mmHg.
- Flow 0.6 L/min: Losing 26% of flow
- Flow 0.2 L/min: Losing 83% of flow …!
Evaluation of shunting flow differences in varied conditions in a simulated adult CPB model during normothermia.

Fuwai Hospital & Cardiovascular Institute, Peking

Flow Left To The Patient of 5000 ml/min

<table>
<thead>
<tr>
<th>Shunts</th>
<th>Flow in arterial line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampel line</td>
<td>4750 ml/min</td>
</tr>
<tr>
<td>3/16</td>
<td>4010 ml/min</td>
</tr>
<tr>
<td>3/16 + sampel line</td>
<td>3800 ml/min</td>
</tr>
<tr>
<td>1/4 + sampel line</td>
<td>1000 ml/min</td>
</tr>
<tr>
<td>1/4 + 3/16</td>
<td>800 ml/min</td>
</tr>
<tr>
<td>All</td>
<td>400 ml/min</td>
</tr>
</tbody>
</table>

Shunts in patient

- Venting of arterial blood
  - in peds: easily over 50% of flow.
- Bleeding/suction of arterial blood

- Physiological shunts (a-v)
- Anatomic abnormalities
- Uneven distribution
Inner/outer circle

- Physiological shunts in circulation
- Uneven distribution - Especially in Digestion system
- Makes sVO2 unreliable - if high

Each organ adds to resistance, - or shunting...

Organ distribution

<table>
<thead>
<tr>
<th>Organ relative to Body weight</th>
<th>Blood Flow (ml/min)</th>
<th>Organ flow relative to CO</th>
<th>O₂ consumption (ml/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain 2.0 %</td>
<td>775</td>
<td>15 %</td>
<td>46</td>
</tr>
<tr>
<td>Heart 0.43 %</td>
<td>175</td>
<td>3.3 %</td>
<td>23</td>
</tr>
<tr>
<td>Kidneys 0.43 %</td>
<td>1100</td>
<td>23 %</td>
<td>18</td>
</tr>
<tr>
<td>GI - Liver 2.1 %</td>
<td>1400</td>
<td>29 %</td>
<td>66</td>
</tr>
<tr>
<td>Lung 1.5 %</td>
<td>175</td>
<td>3.5 %</td>
<td>5</td>
</tr>
<tr>
<td>Muscle 39.7 %</td>
<td>1000</td>
<td>19 %</td>
<td>64</td>
</tr>
<tr>
<td>Rest 55.3 %</td>
<td>375</td>
<td>9.7 %</td>
<td>33</td>
</tr>
</tbody>
</table>
FLOW evaluation

Adjustments according to:

• Blood pressure
• SvO₂
• BE
• Lactate
• Diuresis

Flow measurement

• Calculations from RPM
• Bucket and stop watch….
• Ultrasound, Transit Time
• Conductivity
• Accuracy?

Conclusions

• Perfusionist has not complete control!
• Pump flow ≠ CO
• Beware of shunts combined with high pressure and low flow (peds)
• Arterial line flow should be measured
• Clinical assessment of sufficient flow
How much flow does the patient need?

Oxygen delivery
- Flow
- Hct
- Sat
- Consumption

Adjustments to:
- Age
- BMI
- Muscle/fat
- Sex
- Temperature

\[ \text{VO}_2 = Q \times [\text{Hgb}] \times (\text{SaO}_2 - \text{SvO}_2) \]

Calculate EBF

**EBF** in adults: 1.8 - 2.8 x BSA (L/min/m²)
**EBF** in pediatrics: 2.4 – 3.2 x BSA

**EBF** from weight alone:
- <3kg: 200 ml/kg/min
- 3-10kg: 150 ml/kg/min
- 10-15kg: 125 ml/kg/min
- 15-30kg: 100 ml/kg/min
- 30-55kg: 75 ml/kg/min
- 55-75kg: 65 ml/kg/min
- 75-100kg: 60 ml/kg/min
- >100kg: 50 ml/kg/min
BSA Calculations

**Dubois:** \(0.20247 \times \text{Height(m)}^{0.725} \times \text{Weight(kg)}^{0.425}\)

**Mosteller:** \((\frac{\text{Height(cm)} \times \text{Weight(kg)}}{3600})^{\frac{1}{3}}\)

**New (weight)** \(\text{BSA} = \frac{4xW+7}{(90+W)}\)

**Simple** estimate: \((H + W - 60) / 100\)

Even more simple (adults): \(W / 40\)

---

**Flow vs Temperature**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Metabolism</th>
<th>Min. Flow/BSA</th>
<th>Max. Arrest</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>100 %</td>
<td>2.4</td>
<td>2 min</td>
</tr>
<tr>
<td>32</td>
<td>61 %</td>
<td>2.0</td>
<td>5 min</td>
</tr>
<tr>
<td>28</td>
<td>41 %</td>
<td>1.6</td>
<td>10 min</td>
</tr>
<tr>
<td>20</td>
<td>18 %</td>
<td>1.0</td>
<td>30 min</td>
</tr>
<tr>
<td>18</td>
<td>15 %</td>
<td>0.9</td>
<td>35 min</td>
</tr>
<tr>
<td>10</td>
<td>7 %</td>
<td>0.6</td>
<td>60 min</td>
</tr>
</tbody>
</table>
Optimal Perfusion During Cardiopulmonary Bypass: An Evidence-Based Approach
Glenn S. Murphy, MD*,
Eugene A. Hessel II, MD†, and
Robert C. Groom, MS, CCP‡

Table 4. Clinical Studies Examining the Effect of Pump Flow Rate on Central Blood Flow and Metabolism

<table>
<thead>
<tr>
<th>Study</th>
<th>No of Patients</th>
<th>Flow rate</th>
<th>Temperature</th>
<th>Acid-base management</th>
<th>MAP</th>
<th>Results (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cook et al.</td>
<td>30</td>
<td>1.2-2.3 L min⁻¹</td>
<td>27°C</td>
<td>a-stat</td>
<td>80-39</td>
<td>No difference in mean CRF or CBR in high or low flows</td>
</tr>
<tr>
<td>Gower et al.</td>
<td>57</td>
<td>1.0-2.2 L min⁻¹</td>
<td>27°C</td>
<td>a-stat</td>
<td>45-75</td>
<td>No change in regional CRF or CBR in differing pump flow rates</td>
</tr>
<tr>
<td>Rogers et al.</td>
<td>24</td>
<td>1.75-2.25 L min⁻¹</td>
<td>27°C</td>
<td>a-stat and pH stat</td>
<td>68-75</td>
<td>No difference in CRF or CBR in differing pump flow rates</td>
</tr>
<tr>
<td>Sorensen et al.</td>
<td>21</td>
<td>40-70 mL kg⁻¹ min⁻¹</td>
<td>27°C</td>
<td>pH stat</td>
<td>58-73</td>
<td>CRF increased proportionally to flow rate</td>
</tr>
</tbody>
</table>

MAP = mean arterial pressure; CRF = cardiac rect flow; CBR = coronary blood rate.