Optimized Perfusion Management and Patient Outcome

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University of Colorado Hospital

- Main hospital in University of Colorado Health System
  - University Hospital – Aurora, Colorado
  - Poudre Valley Hospital – Ft. Collins, Colorado
  - Medical Center of the Rockies – Loveland, Colorado
  - Memorial Hospital – Colorado Springs, Colorado

- The only academic hospital on the eastern Rocky Mountain range

- Ranked #1 in quality by the University Health Consortium

- Ranked one of the top hospitals in the USA by US News and World Report

- ≈ 700 CPB procedures per year (all adult)
What does optimized perfusion management mean to you?

- Reduced Hemodilution
  - Patient size matched extracorporeal circuits “prescriptive circuit design”?
  - Autologous priming?
  - Restrictive transfusion?

Is optimized perfusion more than just how small you can make your circuit?
Matching ECC to the Patient

Benefits

- Increased use of small adult oxygenators from 39 to 63%
- Raised average hematocrit nadir from 8.38 to 8.76 g/dL
- Reduced PRBC transfusion
  - Females 1.5 to 1.74 M2 BSA
  - Males 1.75 to 1.99 M2 BSA
- Blood flow selection should be made on lean body mass (LBM)
3 Pillars of Optimized Perfusion

Equipment Selection
- Optimized Adult Oxygenator
- GME Protection

ECC Management
- Dynamic Operating Volume
- Suction Blood Management

Data Driven Management
- CONNECT™
- Goal Directed Perfusion (GDP)
Sorin Primox

- 2006 to 2013
- Only adult oxygenator
- 3/8 arterial and 3/8 venous
- 27 μ Sorin D731 filter
- VAVR
- Revolution centrifugal pump
- 1400 ml priming volume
- DMS Data Management

Sorin Inspire

- March 2013 MAS
  - Inspire 8
  - Inspire 6
- Transition Q4 2013
  - Increase use each Q
  - Inspire 6F only adult oxygenator
- 850 ml priming volume
  - 3/8 " A-V loop
  - Revolution centrifugal
  - VAVR
- 900 + Inspire 6 cases
- CONNECT with GDP
What size oxygenator do you need?

- 15% Isolated CABG
- 27% Isolated single valve
- 37% Complex procedures
- 69% of patients had predicted blood flow < 5 LPM
- 23% 5 – 5.5 LPM
- 8% > 5.5 LPM
- Smallest Patient
  - 149 cm, 48 Kg, 1.4 M² BSA, BMI 22
- Largest Patient
  - 193 cm, 200Kg, 3.3 M² BSA, BMI 55
- Average CPB time 173 minutes
  - Longest pump run = 7 hours 43 min (463 min)
Index of Oxygenator Design Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Quadrox</th>
<th>Quadrox SA</th>
<th>Rx 15</th>
<th>Rx 25</th>
<th>Fusion</th>
<th>Inspire 6</th>
<th>Inspire 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area (M²)</td>
<td>1.8</td>
<td>1.5</td>
<td>1.5</td>
<td>2.5</td>
<td>2.5</td>
<td>1.4</td>
<td>1.75</td>
</tr>
<tr>
<td>HE area (M²)</td>
<td>0.4</td>
<td>0.3</td>
<td>0.14</td>
<td>0.22</td>
<td>0.4</td>
<td><strong>0.43</strong></td>
<td><strong>0.43</strong></td>
</tr>
<tr>
<td>Combined SA (M²)</td>
<td>2.2</td>
<td>1.8</td>
<td>1.64</td>
<td>2.72</td>
<td>2.9</td>
<td>1.83</td>
<td>2.18</td>
</tr>
<tr>
<td>Max Flow (LPM)</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td><strong>6</strong></td>
<td>8</td>
</tr>
<tr>
<td>Static Priming Volume (ml)</td>
<td>215</td>
<td>175</td>
<td>135</td>
<td>250</td>
<td>260</td>
<td>184</td>
<td>219</td>
</tr>
</tbody>
</table>

Sorin Inspire 6 is the only small adult oxygenator rated to 6 LPM covering > 97% of patients

Same heat exchanger surface area as Inspire 8

The Inspire family is the most efficient oxygenator when you compare rated flow to total surface area exposure.
Can an optimized oxygenator serve all patients?

- Oxygen Transfer
  - Range = 147-420 ml O²/min
  - Mean = 252 (58.9) ml O²/min

- % Oxygen Transfer Utilization
  - 5 - 87% of oxygenator
  - Average 35%

- Sorin Inspire 6 is a capable of supporting all patients while providing a reduced FSA exposure

- Using GDP adds an increased level of safety
Factors and Management of AKI

Cardiopulmonary Bypass-associated Acute Kidney Injury

Avinash B. Kumar, MD; Manish Suneja, MD
Anesthesiology 2011: 114:964-70

**Intraoperative Factors:**
- CPB-SIRS response
- Emboli from CPB
- Hemodynamic alterations

**Intraoperative Strategies:**
- Minimize hemodilution
- MAP 50 – 70 mmHg
- Optimize Flows: 2.2 – 2.5 (Do2i)
- Minimize CPB time
Equipment selection: GME...size matters

- 5 year prospective study
- n = 169
- Phase 1
  - 105 u venous
  - 40 u ALF
- Phase 2
  - Stop using unprimed venous line
- Phase 3
  - Observational
- Phase 4
  - 40 u venous filter
  - 27 u ALF

87.9% Reduction in GME
Integrated Filter Design

- Integrated filter with bubble trap design in combination with a 40 micron venous return filter had the lowest embolic volume at both 3.5 and 5 L/min flow.

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**Figure 5.** Total emboli volume was lower after the venous reservoir of the SYN40, followed by the FX, the SX, and RX, and the SYN102 oxygenators. Emboli volume increased at higher flow and pressure (p < .001). (SX: Capiox SX25RX oxygenator, RX: Capiox RX25R oxygenator, FX: Capiox FX25R oxygenator, SYN102: Synthesis oxygenator with original venous reservoir, SYN40: Synthesis oxygenator with modified venous reservoir.)
Compared two oxygenator designs with integrated arterial filters

- Terumo FX 25 and Sorin Synthesis
  - Fiber bundle screen filter wrap v. Separate filter chamber with screen filter

- C-reactive protein, INR, aPTT, Fibrinogen, albumin, total proteins
- Outcomes: Blood loss, transfusion rates

- Separate filter chamber design
  - Decreased blood loss (p = 0.009)
  - Decreased red cell transfusion (p = 0.008)
  - Decreased FFP (p = 0.0001)
  - Decreased c-reactive protein (p = 0.034)

Separate filter chamber designed showed less inflammation and better preservation of coagulation proteins."
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Reducing GME

- Separate Filter Chamber Design
  - Acts like traditional arterial line filter
- Screen filtration
- Buoyancy
  - Reduction in velocity
  - Active purge
- Maintains integrated filter convenience
  - Priming
  - Same volume as small adult ALF
  - Circuit configuration options
    - Place close to the table
    - Protection
Reducing GME

- Improved suction blood management with dual reservoir
  - Separation of high inflammatory load suction blood for alternative processing
    - Autotransfusion v. direct infusion
  - Separation of high v. low GME load
    - Aortic root vents v. LV vent and pump suction
- Better waterfall blood handling (reduced GME generation)
- Antifoam avoidance
- Increased circuit protection
  - Pre / Post heparinization
Venous Filtration Pore Size

<table>
<thead>
<tr>
<th>Oxygenator</th>
<th>Micron</th>
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<tbody>
<tr>
<td>Inspire</td>
<td>40</td>
</tr>
<tr>
<td>Terumo</td>
<td>47</td>
</tr>
<tr>
<td>Affinity</td>
<td>150</td>
</tr>
<tr>
<td>Fusion</td>
<td>105</td>
</tr>
<tr>
<td>Quadrox</td>
<td>150</td>
</tr>
<tr>
<td>Bag</td>
<td>105</td>
</tr>
<tr>
<td>ROCsafe</td>
<td>170</td>
</tr>
<tr>
<td>Medtronic RH</td>
<td>175</td>
</tr>
<tr>
<td>MECC</td>
<td></td>
</tr>
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</table>

Oxygenator alone is not enough to remove GME. Efficiency ranges from 40 ≈ 98% depending on design.
Pillar 2: Improved ECC Management

Dynamic Operating Volume: total effect on hemodilution

- The total volume required to reach the rated flow
- Static prime volume of components
- Volume not available for patient management
  - Venous down tube
  - Venous filter holdup
  - Minimum operating volume
  - Arterial filter
Dynamic Operating Volume

- The Sorin Inspire 6F can meet the dynamic operating volume of traditional minimal “closed” ECC systems
- Same DOV with separate ALF
  - D731 (27μ ALF) + Inspire 6M
- Lower static priming components improve the effectiveness of autologous priming techniques

Some data in this slide courtesy of G. Meyers
• If you choose a non-integrated low prime arterial filter:
• Same DOV
• Expanded application with the Inspire 6
  • Inspire = 6 LPM
  • RX 15 = 5 LPM

• Does not include volume of centrifugal pump
• Does not include A-V loop
Improved DOV of Sorin Inspire 6 leads to decreased transfusion and reduced acute kidney injury

- Inspire 6 v. Compactflo EVO or EOS 905
- Conventional circuit prime volume = 775 ml
- Inspire 6 priming volume = 624 ml
- 151 ml prime saving
- N = 383 Inspire 6 patients

- Reduced transfusion rate
- Reduced transfusion volume (# units)
- Reduced acute kidney injury (AKI)

Small improvements in dynamic operating volume can have significant patient outcome results

- 1% drop in hematocrit = 7% increase risk of AKI

Ranucci M., Pistuddi V., Carboni G., Effects of priming volume reduction on allogeneic red blood cell transfusions and renal outcomes after heart surgery., Perfusion, May 2014
Improved Dynamic Operating Volume = Reduced Hemodilution

- Improved static priming volume
  - More complete autologous priming (retrograde + antegrade)
  - Average net priming volume
    - 32% reduction
- Improved operating volume
  - Increased working volume
  - Reduced added volume on CPB
    - 70% reduction in added volume
    - Reduced hemodilution
    - Reduced transfusion requirement

### Perioperative Volume Management

<table>
<thead>
<tr>
<th></th>
<th>Anesthesia Volume</th>
<th>Net ECC Prime Volume</th>
<th>Volume Added on CPB</th>
</tr>
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<tbody>
<tr>
<td>2014 Q3</td>
<td>1751</td>
<td>586</td>
<td>749</td>
</tr>
<tr>
<td>2014 Q2</td>
<td>1726</td>
<td>675</td>
<td>1336</td>
</tr>
<tr>
<td>2014 Q1</td>
<td>1704</td>
<td>718</td>
<td>1605</td>
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<tr>
<td>2013 Q4</td>
<td>1889</td>
<td>676</td>
<td>2012</td>
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<tr>
<td>2013 Q3</td>
<td>1735</td>
<td>868</td>
<td>2517</td>
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</tbody>
</table>

n = 535
Value of Improved DOV

- Improved Dynamic Operating Volume (DOV) yields more usable volume for blood flow management
- % Hematocrit Drop
  - Baseline 36%
  - Inspire Group 12%
- Chance of a transfusion free experience (95% CI)
  - Patient baseline hematocrit 34% to 27%
- Avoids transfusion in smaller more anemic patients

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Inspire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Tx (U)</td>
<td>2.8</td>
<td>0.63</td>
</tr>
<tr>
<td>$f$</td>
<td>46</td>
<td>20</td>
</tr>
</tbody>
</table>
Effect of Sorin Inspire and Goal Directed Perfusion (GDP) on PRBC Transfusion

PRBC Utilization Rate

- Baseline PRBC Transfusion Rate
  - 46%
  - Volume mean 2.8 units

- End of Q3 2014 PRBC Rate
  - 20%
  - Volume mean 0.63 units

- 50% reduction in frequency of PRBC
- 77% reduction in volume of PRBC units
More than DMS version 2
Sorin CONNECT™ with GDP Monitor

- More than a data collection and electronic record tool
- Perfusion management tool
  - Data to perfusion calculations
  - Grouped in meaningful arrangement
- University of Colorado format
  - CI, relative flow and SVR
  - Temperature gradient $\Delta T$
  - $\text{CrSO}_2$ and MAP
  - Continuous display of $\text{DO}_2$ along with normal perfusion parameters
Value of Electronic Perfusion Records

- Reduce practice variation
- Assist with QI projects
More accurate data

Better reproduction of CPB

More time to concentrate on actual patient management.
<table>
<thead>
<tr>
<th>Measurement Point</th>
<th>9:42 AM</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2exh</td>
<td>28 mmHg</td>
<td>DO2i 425.72 ml/min/m^2</td>
</tr>
<tr>
<td>Ve</td>
<td>2 l/min</td>
<td>VO2i 32.71 ml/min/m^2</td>
</tr>
<tr>
<td>Qb</td>
<td>4.42 l/min</td>
<td>VCO2i 35.78 ml/min/m^2</td>
</tr>
<tr>
<td>PaO2</td>
<td>339 mmHg</td>
<td>DO2i/VCO2i 11.8990</td>
</tr>
<tr>
<td>SvO2</td>
<td>90 %</td>
<td>VCO2i/VO2i 1.0937</td>
</tr>
<tr>
<td>Hct_gdp</td>
<td>36 %</td>
<td>VO2i/DO2i 0.08</td>
</tr>
<tr>
<td>Pvo2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SaO2</td>
<td>98 %</td>
<td></td>
</tr>
<tr>
<td>Body Surface Area (BSA)</td>
<td>1.8 m^2</td>
<td></td>
</tr>
</tbody>
</table>
Optimizing oxygen delivery

- N = 140 patients
- Control group HCT = 30%
- GDP group HCT = 27%
- Adjust CI to maintain same DO$_2$

Anemia management
- Select appropriate blood flow
- Identify when to transfuse
  - Unable to maintain DO$_2$i
  - DO$_2$i/VCO$_i$ < 4.8
  - Oxygen extraction ratio > 35%
- Identify volume to transfuse
  - Only give what you need
  - Physiological basis for PRBC transfusion

Continuous GDP information reduces variation
Routine GDP™ Monitoring and AKI

- Baseline AKI rate before July 2014 = 25%
- July 50% use of GDP
- July – Dec average AKI = 8.4%
- 12 month (July 2015) AKI = 5%

80% reduction in rate of new AKI
Conclusions

- Sorin Inspire 6F (6 LPM) small adult oxygenator
  - Reduced surface area exposure
    - More than 30% reduction on full size adult oxygenators
  - No compromise in heat exchange
    - Inspire 6 = Inspire 8
- Improved GME handling
  - Dual chamber reservoir design
  - Oxygenator design
  - Integrated filter chamber design
- Optimize extracorporeal circuit management
  - Improved dynamic operating volume
  - Goal Directed Perfusion
    - Base blood flow and hemoglobin management decisions based on real time patient specific information