Considerations in Circuit Miniaturization

The AmSECT 40th International Conference
Pediatric Track

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Syracuse, NY
Objectives

- Investigate the long held dogma is “smaller is better”.
  - Motivations for miniaturization

- Discuss techniques to miniaturize the neonatal and pediatric CPB circuits.

- Explore “Second Generation” concepts of pediatric pump oxygenators
  - Safety considerations
The Problem -  
A matter of proportions

<table>
<thead>
<tr>
<th></th>
<th>Pt. Blood Volume</th>
<th>Circuit Prime Volume</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 kg Adult</td>
<td>4500 ml</td>
<td>1500 ml</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7059 ml)</td>
<td></td>
</tr>
<tr>
<td>3 kg Neonate</td>
<td>255 ml</td>
<td>400 ml</td>
<td>157%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(84.1 ml)</td>
<td></td>
</tr>
</tbody>
</table>
Motivation for circuit miniaturization

- **Avoidance of donor blood**
  - risk of infection
  - immunological problems
  - metabolic problems
  - Availability and cost
  - Parental preference

- **Avoidance of hemodilution**
  - capillary leak/edema
  - clotting mechanisms disturbed

- **Reduction of synthetic surface area**

Martin Elliott
Perfusion: 1993;8:81-86
Motivation for circuit miniaturization


Blood-biomaterial interaction studies using a rodent recirculation model.

Does reducing the expanse of exposed biomaterial reduce the inflammatory response?

Reducing surface area of PVC tubing produced less CD11b Integrin expression on neutrophils.

80 infants (mean 4.6 ± 1.6 kg) studied with small circuit
Total prime volume = 205 ml
Mean RBCs used in prime = 93.5 ± 60 ml  (25% asaunginious)
Mean post-op RBCs used = 202 ± 67 ml  (3.7% no RBCs)
Mean FFP used in prime = 2 ± 19 ml  (85% no FFP )
Mean post-op FFP used = 62 ± 72 ml  (37% no FFP at all)

No MUF used
Blood use is inevitable. Circuitry should be reasonably small using available components and historical perfusion parameters & norms.

Smaller is better. Bloodless CPB in infants is possible, we should work toward this. Apply new concepts to attain miniaturization.
Conventional approaches to miniaturization

“Priming Volume” - defined
How can we reduce the priming volume?

- Modify tubing dimensions
  - Length
  - Diameter
Shorten line lengths

√ Minimize the deadspace in the circuit

√ Reposition to optimize tubing lengths
## Decrease tubing diameters

<table>
<thead>
<tr>
<th>Tubing</th>
<th>Volume (cc/foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot;</td>
<td>2.5</td>
</tr>
<tr>
<td>3/16&quot;</td>
<td>5.0</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>9.65</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>21.7</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>38.6</td>
</tr>
</tbody>
</table>
Tubing Diameter

1/8"

1/4"

3/16"

3/8

1/2"

1/15/1998 12:47
**Tubing flow ranges**

<table>
<thead>
<tr>
<th>Arterial Line</th>
<th>1/8”</th>
<th>300 - 400 cc/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3/16”</td>
<td>400 - 1000 cc/min</td>
</tr>
<tr>
<td></td>
<td>1/4”</td>
<td>1000 - 2200 cc/min</td>
</tr>
</tbody>
</table>

Disclaimer: Values advocated by other centers. We are not necessarily recommending this.
Most centers will use 1/4” venous line up to about 1500 ml/min.

Augmented venous drainage has changed that paradigm
How can we reduce the priming volume?

- **Modify tubing dimensions**
  - Length
  - Diameter

- **Component selection**
  - Oxygenator
  - Arterial line filter
  - Cardioplegia system
Components

• Oxygenator Unit
• Arterial Line Filter
• Cardioplegia System
Components - Oxygenators Unit

CONSIDERATIONS

• Venous reservoir

• Design

• Versatility

• Biocompatibility
<table>
<thead>
<tr>
<th></th>
<th>Priming Vol. (ml)</th>
<th>Q Rating (ml/min)</th>
<th>Membr. Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobe Micro</td>
<td>52</td>
<td>800</td>
<td>0.33</td>
</tr>
<tr>
<td>Sorin Lilliput I</td>
<td>60</td>
<td>800</td>
<td>0.34</td>
</tr>
<tr>
<td>Medtronic MiniMax</td>
<td>140</td>
<td>1500</td>
<td>0.6</td>
</tr>
<tr>
<td>Terumo 308</td>
<td>80</td>
<td>800</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Cobe Micro

Sorin Lilliput I
Arterial Line Filters

Pall LPE 1440

Capiox AFO2
How can we reduce the priming volume?

- Modify tubing dimensions
  - Length
  - Diameter
- Component selection
- Elimination(??)

arterial line filter
hemoconcentrator/MUF circuit
BCPS system
Elimination of Arterial Line Filter?

The ALF can represent 10 - 20% of the entire Priming volume of a Pediatric CPB circuit

96% of pediatric centers use arterial line filtration

Groom R, 1995, Perfusion 10(6):393-401
Blood Cardioplegia Systems

What are the options?
... In the long-term the whole basic concepts of venous return and arterial pumping must be re-addressed.
Re-design the pump console

What is the current “standard” CPB console?
“Second generation pump oxygenator”

CARDIOPULMONARY BYPASS
IN NEONATES, INFANTS and
YOUNG CHILDREN

Jonas R and Elliott M

Chapter 16  Kirklin, Raible, Blackstone

Priming volume and other aspects of
pump oxygenators for neonates and
infants
The Duke mini-circuit

Oxygenator and Pumps at patient Level.

Requires the use of Vacuum assisted Venous drainage.
The Duke mini-circuit

Oxygenator and Pumps at patient Level.

Requires the use of Vacuum assisted Venous drainage.
Compared to standard console
Mini circuit - small roller pumps
Mini-circuit cardiopulmonary bypass with vacuum assisted venous drainage: feasibility of an asanguineous prime in the neonate

• C Lau et al. *Perfusion* 1999; 14: 389-396

• 10 x 1-week old piglets
  – 5 conventional circuit
  – 5 “mini-circuit”

• Results
  – Blood requirements less (47 ± 5.8 ml vs. 314 ± 31.6)
Clinical Applications

Dr. Y Takahashi
Sakakibara Heart Institute
100 infants (3.3 - 4.9 kg)
VSD/PH
Mean lowest Hct = 15%
Post-op Day 2 = 28%

94% had no blood transfusions

No neurological complications
Psychomotor development index scores near normal.

Technowood® System
Barrier sheet

Technowood® System
Vacuum-Assisted Venous Drainage: To Air or Not to Air, That is the Question. Has the Bubble Burst?

How do pediatric perfusion circuits handle entrained venous air?

Air entrainment in venous line results in air emboli detection in the arterial line even under gravity conditions.

With VAVD, this effect to significantly more pronounced.
Limits of Miniaturization
Limits of Miniaturization
# Limits of Miniaturization

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>Species</th>
<th>B.V. (ml)</th>
<th>P. V. (ml)</th>
<th>% diff.</th>
</tr>
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<tr>
<td>75</td>
<td>Adult</td>
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<tr>
<td>0.5</td>
<td>Rat</td>
<td>40</td>
<td>10</td>
<td>25%</td>
</tr>
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Optimal CPB Conditions