Pediatric extracorporeal life support systems and Pediatric cardiopulmonary perfusion systems: Now and future

Asist.Prof.Dr. Tolga KURT
Canakkale Onsekiz Mart University
Turkey

International Conference and Exhibition on Pediatric Cardiology
August 25-27, 2015 Valencia
Background - History

- CPB
- ECMO-ECLS
- VAD
- TAH
The first heart-lung machine (HLM) which was made by Gibbon
The new HLM machines
One of the first machines and surgical team
Now
Differences between pediatric and adult Cardiopulmonary Perfusion

- Pediatric organ systems are not developed sufficiently as adults.
- The size of the organs are smaller than the adults
- The rate of metabolism is higher than adults ↔ higher perfusion rate is needed.
- The frequent need of intracardiac access
- Presence of abnormal anatomy and physiology
Differances between **pediatric** and **adult** cardiopulmonary bypass (CPB) procedures

- Extreme hypothermia, hemodilution and perfusion flow rate values
- Pathological anatomy → operation technical changes
- CPB circuit extremely large compared to body mass index
- The prime volume is more than the total blood of newborns and infants.
- Large body mass index differences observed in the cases → selection of appropriate materials required in each case.
Pediatric CPB Complications

- We must lower the prime volume
- We must lower the surface area which the blood contacts.
- We must reduce the size of the circuit components
Prime Volume

Adults → 25-30 % Of the total blood volume

Neonates → 2-3 times Of the total blood volume

To prevent excessive hemodilution → Donor blood can be add to prime volume
Sanguineous prime volume

- Blood-borne infections
- Reinforcement of inflammatory reaction
- Transfusion-induced acute lung injury
- Pulmonary hypertension
- The organ perfusion disorders due to rheological properties
- Low cardiac index
Our Target:

- Lower prime oxygenator volume
- Reducing the size of the venous line
- Reducing the size of the circuit
- Arterial line filter
- Venous Reservoir Level

↓ ↓ ↓ ↓ ↓

The circuit prime volume reduction and non *sanguineous* prime volume
ALF: Arterial line filter
McRobb CM, Mejak BL, Ellis WC, Lawson DS, Twite MD.
Recent Advances in Pediatric Cardiopulmonary Bypass. Semin Cardiothorac Vasc Anesth.
Pediatric CPB pumps

- Roller Pumps
- Centrifugal Pumps
Roller Pumps

+++ With small diametered lines, the prime volume is low
+++ Sensitive flow control even at low flow rates
--- Hemolysis or damage to the other formed elements of the blood
--- Roller pump induced tubing tear of polyvinylchloride and silicone rubber tubing
--- Inability to provide appropriate position

The new generation heart lung machine can be given the required position.
Centrifugal Pumps

+++ More mobile
+++ Less hemolysis or damage to the other formed elements of the blood
+++ Reducing the flow line to prevent the high pressure in arterial line obstructions
--- High prime volume
--- Insufficient sensitivity at low flow rates
# New generation centrifugal pumps

<table>
<thead>
<tr>
<th></th>
<th>Prime volume (ml)</th>
<th>Max Flow (L/min)</th>
<th>Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medos Deltastream DP3</td>
<td>16</td>
<td>8</td>
<td>3/8”</td>
</tr>
<tr>
<td>Medos s.pump</td>
<td>17</td>
<td>8</td>
<td>3/8”</td>
</tr>
<tr>
<td>Levitonix CentriMag</td>
<td>31</td>
<td>10</td>
<td>3/8”</td>
</tr>
<tr>
<td>Maquet ROTAFLOW</td>
<td>32</td>
<td>10</td>
<td>3/8”</td>
</tr>
<tr>
<td>Medtronic Affinity CP</td>
<td>40</td>
<td>10</td>
<td>3/8”</td>
</tr>
<tr>
<td>Terumo CAPIOX SP</td>
<td>45</td>
<td>8</td>
<td>3/8”</td>
</tr>
<tr>
<td>Medtronic BP-50 Bio-Pump</td>
<td>48</td>
<td><strong>1.5</strong></td>
<td><strong>1/4”</strong></td>
</tr>
<tr>
<td>Sarns disposable centrifugal pump</td>
<td>48</td>
<td>10</td>
<td>3/8”</td>
</tr>
<tr>
<td>Sorin RevOlution</td>
<td>52</td>
<td>8</td>
<td>3/8”</td>
</tr>
</tbody>
</table>
Pediatric Oxygenators

Structure → Holow fiber
Gas exchange surface → porous polypropylene
Gases transmit from the pores → through blood
Erythrocytes and plasma does not transmit !!
Pediatric Oxygenators
Wide temperature range (10 °C - 40 °C)
Wide flow range (0 - 200 ml / kg / min)
Htc wide range (15% - 40%)
Wide range of line pressure
Wide gas flow range
↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓
Despite its small surface area, effective gas exchange, even at high flow.
<table>
<thead>
<tr>
<th>Pediatric Oxygenators</th>
<th>Priming volume (ml)</th>
<th>Surface area (m²)</th>
<th>Max Flow (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorin D100 Kids</td>
<td>31</td>
<td>0.22</td>
<td>0.7</td>
</tr>
<tr>
<td>Maquet QUADROX-i Neonatal</td>
<td>38</td>
<td>0.38</td>
<td>1.5</td>
</tr>
<tr>
<td>Terumo CAPIOX BabyRx</td>
<td>43</td>
<td>0.50</td>
<td>1.5</td>
</tr>
<tr>
<td>Medtronic Affinity Pixie</td>
<td>48</td>
<td>0.67</td>
<td>2</td>
</tr>
<tr>
<td>Medos Hilite 1000</td>
<td>57</td>
<td>0.39</td>
<td>1</td>
</tr>
<tr>
<td>Sorin Lilliput I</td>
<td>60</td>
<td>0.34</td>
<td>0.8</td>
</tr>
<tr>
<td>Maquet QUADROX-i Pediatric</td>
<td>81</td>
<td>0.80</td>
<td>2.8</td>
</tr>
<tr>
<td>Sorin D101 Kids</td>
<td>87</td>
<td>0.61</td>
<td>2.5</td>
</tr>
<tr>
<td>Medos Hilite 2800</td>
<td>98</td>
<td>0.80</td>
<td>2.8</td>
</tr>
<tr>
<td>Medtronic Minimax Plus</td>
<td>149</td>
<td>0.80</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Pediatric Tubing Sets

- Tubing sets → 75% of the prime volume
- The most important step in reducing the tubing set volume → Reducing the length and diameter of the tubing set:
  - Approimation of the pump to the patient → about 29% reduction in the volume of prime
- Tubing set diameter reduction → the resistance to flow increase → assisted venous drainage
- Shortening of the tubing set → decrease of the resistance
Pediatric Arterial Filters

Disadvantages:
------High prime volume
------A large foreign surface
------The difficulty of removing the air bubbles

<table>
<thead>
<tr>
<th>Pediatric Arterial Filters</th>
<th>Priming volume (ml)</th>
<th>Max Flow (L/min)</th>
<th>Pore (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorin D130 Kids ALF</td>
<td>16</td>
<td>0.7</td>
<td>40</td>
</tr>
<tr>
<td>Sorin D131 Kids ALF</td>
<td>28</td>
<td>2.5</td>
<td>40</td>
</tr>
<tr>
<td>Medtronic Affinity Pixie ALF</td>
<td>39</td>
<td>3.2</td>
<td>30</td>
</tr>
<tr>
<td>Terumo CAPIOX ALF AF02</td>
<td>40</td>
<td>2.5</td>
<td>32</td>
</tr>
</tbody>
</table>
Integrated products

- Only reducing the component size is insufficient to reduce prime volume.
- We need integrated component products: oxygenator + arterial filter.

<table>
<thead>
<tr>
<th></th>
<th>Priming volume (ml)</th>
<th>Max Flow (L/min)</th>
<th>Pore (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maquet QUADROX-i Neonatal</td>
<td>38</td>
<td>1.5</td>
<td>33</td>
</tr>
<tr>
<td>Terumo CAPIOX FX05</td>
<td>43</td>
<td>1.5</td>
<td>32</td>
</tr>
<tr>
<td>Maquet QUADROX-i Pediatric</td>
<td>81</td>
<td>2.8</td>
<td>33</td>
</tr>
<tr>
<td>Terumo CAPIOX FX15</td>
<td>144</td>
<td>5.0</td>
<td>32</td>
</tr>
</tbody>
</table>
Integrated products

- No need for an extra prime volume for the arterial filters
- The captured gas bubbles are transferred to the oxygenator gas reservoir by the pressure difference.
- Particulate emboli capture efficiency is similar to standard filters
- Gas emboli capture efficiency is higher than standard filters
Pediatric cardioplegia

- Standard blood cardioplegia
- Del Nido cardioplegia
- Crystalloid cardioplegia
- ------St. Thomas solution------
- ------Custodiol (Histidine-Tryptophan-Ketoglutarate)------
- Microplegia
- ------Quest Biomedical MPS2 Myocardial Protection System (prime 7-35 mL)------
Pediatric Ultrafiltration

It has a porous hollow fiber structure made with polysulfone, molecules Weighting <50-65 kDa can pass.

Aim:
- Reduction of Edema
- Raising hematocrit values
- Removal of electrolyte (potassium)
- Removal of Inflammation mediators, lactate and citrate
<table>
<thead>
<tr>
<th>Pediatric Ultrafiltration</th>
<th>Prime (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medivator Hemocor HPH Jr</td>
<td>8</td>
</tr>
<tr>
<td>Medivator Hemocor HPH Mini</td>
<td>14</td>
</tr>
<tr>
<td>Maquet BC20 Plus</td>
<td>17</td>
</tr>
<tr>
<td>Medos Hemofilter Pro 20</td>
<td>17</td>
</tr>
<tr>
<td>Sorin Dideco DHFO.2 Hemoconcentrator</td>
<td>30</td>
</tr>
<tr>
<td>Medivator Hemocor HPH 400</td>
<td>34</td>
</tr>
<tr>
<td>Terumo CAPIOX Hemoconcentrator</td>
<td>35</td>
</tr>
<tr>
<td>Medos Hemofilter Pro 60</td>
<td>52</td>
</tr>
<tr>
<td>Maquet BC60 Plus</td>
<td>65</td>
</tr>
</tbody>
</table>
ECMO-ECLS
(Extracorporeal Membrane Oxygenation - ExtraCorporeal Life Support)

The aim is to provide sufficient time and appropriate environment for the restoration of myocardial and lung damage.

- ECLS
- ECMO
- ECCO2R (Extracorporeal carbon dioxide removal)
- VAD (ventricular assist device)
Roller pumps are the most commonly used.

+++
Inexpensive

++++ Reliable

++++ Laminar flow

----- Hemolysis

----- Spallation and tube rupture

Spallation:
The sloughing off of plastic and silastic tubing particles into the lumens of tubing through the erosive and fatiguing action of rollers in the pump head.
Spallation and tube rupture

PVC Tubing

1 Hr. at 15° C
1 Hr. Rewarming to 37° C
2 Hrs. at 37° C
ECMO PUMPS

To prevent excessively high and low pressure formation → continuous measurement of arterial and venous pressure line

<table>
<thead>
<tr>
<th></th>
<th>Prime volume (mL)</th>
<th>Connector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medtronic Bladder Reservoir R-14</td>
<td>35</td>
<td>1/4”</td>
</tr>
<tr>
<td>Medtronic Bladder Reservoir R-38</td>
<td>35</td>
<td>3/8”</td>
</tr>
</tbody>
</table>
ECMO PUMPS

Centrifugal Pumps:

- ++++ Less traumatic to blood cells
- ------ Sensitive preload and afterload
- ------ Insufficient flow due to the high internal resistance of the silicon membrane oxygenators.
- ------ The risk of thrombosis in long-term use (5-7 days).
ECMO Oxygenators

- Porous polypropylene hollow fiber oxygenators → In long-term use: wetting of the membrane structures, leakage of plasma, dysfunction.
- For long-term usage → non-porous silicon membrane oxygenators
- There are no holes in the silicon membrane. Gases diffuse through the blood from the silicon
ECMO Oxygenators

- Spiralcoiled structure → high resistance to blood flow → blood oxygenator transition speed slows down and increases gas transfer
- Internal heat exchanger available → also adding circuit heat exchanger unit → increase in the prime volume of the system

<table>
<thead>
<tr>
<th>Silicone membrane oxygenators</th>
<th>Prime volume (mL)</th>
<th>Surface area (m2)</th>
<th>Max Flow (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avecor/Medtronic 0800</td>
<td>100</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Avecor/Medtronic 1500</td>
<td>175</td>
<td>1.5</td>
<td>1.8</td>
</tr>
</tbody>
</table>
ECMO Oxygenators

Polymethylpentene porous hollow fiber oxygenator:

+++++ Long-term use (up to 2 weeks)

No largely plasma leakage

+++++ Internal heat exchanger

No increase in prime volume

+++++ Centrifugal pump usage according to their low internal resistance
## ECMO Oxygenators

<table>
<thead>
<tr>
<th>Polymethylpentene oxygenator</th>
<th>Prime volume (mL)</th>
<th>Surface area (m2)</th>
<th>Max Flow (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medos Hilite 800LT</td>
<td>55</td>
<td>0.32</td>
<td>0.8</td>
</tr>
<tr>
<td>Eurosets ECMO NEW BORN</td>
<td>90</td>
<td>0.69</td>
<td>1.5</td>
</tr>
<tr>
<td>Medos Hilite 2400LT</td>
<td>95</td>
<td>0.65</td>
<td>2.4</td>
</tr>
<tr>
<td>Sorin EOS ECMO</td>
<td>150</td>
<td>1.2</td>
<td>5</td>
</tr>
<tr>
<td>Maquet QUADROX-iD ECMO</td>
<td>250</td>
<td>1.8</td>
<td>7</td>
</tr>
</tbody>
</table>
**ECMO Heat Exchangers**

Newborn ECMO → thermoregulation ability is underdeveloped

<table>
<thead>
<tr>
<th>Model</th>
<th>Prime volume (mL)</th>
<th>Max Flow (L/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gish Biomedical HE-3</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Medtronic ECMOtherm II HE</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>Gish Biomedical HE-4</td>
<td>60</td>
<td>2</td>
</tr>
</tbody>
</table>
ECMO Tubing Sets

- **DEHP** in PVC tubes (di (2-ethylhexyl) phthalate) → infertility in long-term usage
- No abnormalities in clinical development for patients
- ECMO with the roller pump → PVC tube line in the pump head → spallation and tube rupture
- Tygon S-65 HL tubes are more resistant to spallation and tube rupture, they can be preferred.
Pediatric circulatory support

- Short-term (<30 days) assistance → ECMO, centrifugal pump or roller pump
- Long-term assistance → Ventricular assist devices (VAD):
  - Parakorporeal pneumatic pulsatile VAD
    - Newborns and infants → Berlin Heart, Medos HIA VAD
    - Adolescents → Thoratec VAD, Heartmate VAD
  - Axial flow devices → MicroMed/DeBakey VAD
Good luck to all of our children, and Godspeed in now and future.

Thank You…
References