ECMO: Decision Making, Preferred Components, and Techniques

Peter D. Wearden, MD, PhD
Associate Professor of Surgery
Director of Mechanical Circulatory Support
Surgical Director Heart / Lung Transplantation
Cardiothoracic Surgery
Children’s Hospital of Pittsburgh of UPMC
Disclosures

- No relevant financial disclosures
- Thoratec Centrimag has FDA HDE approval for 30 day use for right heart support
- All other centrifugal pumps and ECMO systems are FDA 510 K approved for 6 hours of use only
Outline

- ECMO is a 4 letter word
  - Historic Outcomes and Complications
  - Viewed as negative quality outcome indicator

- Has anything changed or can be done better?
  - Equipment
    - Oxygentors, pumps, tubing, components, systems
  - Patient Management
    - Anticoagulation
    - Strategies on ECMO
    - Strategies to wean from ECMO

- Ergo ECMO
<table>
<thead>
<tr>
<th></th>
<th>Study Period</th>
<th>Total Cases</th>
<th>No (%) ECMO</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detroit</td>
<td>1984-1994</td>
<td>NR</td>
<td>66 (3)</td>
<td>57.6%</td>
</tr>
<tr>
<td>Durham</td>
<td>1994-1999</td>
<td>1029</td>
<td>35 (3.4)</td>
<td>61%</td>
</tr>
<tr>
<td>Nashville</td>
<td>1997-2000</td>
<td>1160</td>
<td>50 (4.0)</td>
<td>50%</td>
</tr>
<tr>
<td>Ann Arbor</td>
<td>1995-2000</td>
<td>3306</td>
<td>74 (2.2)</td>
<td>50%</td>
</tr>
<tr>
<td>London</td>
<td>1992-2001</td>
<td>NR</td>
<td>81 (2.5)</td>
<td>49%</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>1995-2001</td>
<td>2598</td>
<td>89 (3.4)</td>
<td>40%</td>
</tr>
<tr>
<td>Toronto</td>
<td>2001-2003</td>
<td>673</td>
<td>36 (5.4)</td>
<td>50%</td>
</tr>
<tr>
<td>Atlanta</td>
<td>2002-2004</td>
<td>950</td>
<td>17 (1.8)</td>
<td>35%</td>
</tr>
</tbody>
</table>

Despite this experience, outcomes have improved little over the last decade.

a. Mortality rates 2004 – 2014: 0 – 30 days of age

<table>
<thead>
<tr>
<th>Year</th>
<th>0-30 Days</th>
<th>0-30 Days Mortality Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>2,598</td>
<td>149</td>
</tr>
<tr>
<td>2005</td>
<td>2,903</td>
<td>155</td>
</tr>
<tr>
<td>2006</td>
<td>3,257</td>
<td>143</td>
</tr>
<tr>
<td>2007</td>
<td>3,621</td>
<td>152</td>
</tr>
<tr>
<td>2008</td>
<td>3,999</td>
<td>150</td>
</tr>
<tr>
<td>2009</td>
<td>4,380</td>
<td>154</td>
</tr>
<tr>
<td>2010</td>
<td>4,685</td>
<td>150</td>
</tr>
<tr>
<td>2011</td>
<td>5,070</td>
<td>150</td>
</tr>
<tr>
<td>2012</td>
<td>5,473</td>
<td>143</td>
</tr>
<tr>
<td>2013</td>
<td>5,920</td>
<td>151</td>
</tr>
<tr>
<td>2014</td>
<td>6,241</td>
<td>151</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Year</th>
<th>31-1 Year</th>
<th>31-1 Year Mortality Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>1,783</td>
<td>153</td>
</tr>
<tr>
<td>2005</td>
<td>1,951</td>
<td>149</td>
</tr>
<tr>
<td>2006</td>
<td>2,141</td>
<td>155</td>
</tr>
<tr>
<td>2007</td>
<td>2,330</td>
<td>185</td>
</tr>
<tr>
<td>2008</td>
<td>2,565</td>
<td>167</td>
</tr>
<tr>
<td>2009</td>
<td>2,808</td>
<td>151</td>
</tr>
<tr>
<td>2010</td>
<td>3,043</td>
<td>162</td>
</tr>
<tr>
<td>2011</td>
<td>3,312</td>
<td>148</td>
</tr>
<tr>
<td>2012</td>
<td>3,571</td>
<td>143</td>
</tr>
<tr>
<td>2013</td>
<td>3,856</td>
<td>177</td>
</tr>
<tr>
<td>2014</td>
<td>4,091</td>
<td>130</td>
</tr>
</tbody>
</table>

1 ELSO Registry Data: January 2015
Despite these outcomes the use of ECMO for cardiac indications continues to increase across all age groups.

1 ELSO Registry Data: January 2014
PubMed Papers: Cardiac ECMO

Number of Papers Published

0 50 100 150 200 250 300

PubMed Papers: Cardiac ECMO

Children's Hospital of Pittsburgh Heart Center
Indications for ECMO

- Left, right, biventricular and pulmonary support
- Low Cardiac Output (Heart Failure)
- Failure to Wean from CPB
- Pulmonary Hypertension
- Refractory Arrhythmias
- Cardiac Arrest (ECPR)
- Respiratory Failure
## ECMO vs VAD

<table>
<thead>
<tr>
<th>Feature</th>
<th>ECMO</th>
<th>VADs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Term Support</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>Right and Left Heart Support?</td>
<td>Yes</td>
<td>Two pumps, increased</td>
</tr>
<tr>
<td></td>
<td></td>
<td>complications</td>
</tr>
<tr>
<td>Pulmonary Support?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Peripheral Cannulation</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rapidly Deployed?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>ECPR?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>All Anatomy?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>All sizes?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Easily Removed at Recovery?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
How has ECMO changed?

- New and better centrifugal pumps
  - Markedly reduced blood cell damage
- Switch to hollow fiber membrane oxygenators from silicone membrane oxygenators and from polypentene to polymethylpentene
  - Superior gas exchange
  - Decreased resistance → centrifugal pumps
  - Decreased prime
  - Decreased RBC, platelet and plasma consumption / damage
E.C.M.O
Pumps and Their Principles

• Roller Pump (Neonatal)
  ▪ Functions on the principle of *Volume Displacement*.

• Centrifugal Pump (Pediatric)
  ▪ Functions on the principle of *Constrained Vortex*.
Roller Pump
(Volume Displacement)

Flow is produced by compressing a segment of tubing between two roller heads, spaced 180 degrees apart, and a back plate. Volume is displaced as the rollers travel the length of the race way.

Raceway with tubing

Roller Heads (180 degrees apart)
Centrifugal Pump
(Constrained Vortex)

- A vortex is formed and energy is transferred to the blood by a rapidly rotating smooth cone
- As blood is expelled at the top of the vortex (outflow), displacement pulls blood into the apex of the vortex (inflow)
- This process is self regulating
  - Preload & afterload dependent
- Centrifugal pumps are ideal for high flow conditions
Traditional Bearings, Hydrodynamic Bearings and MagLev

![Traditional Bearing Diagram]

Hydrodynamic Bearing

![MagLev Diagram]

MagLev
# Pumps

<table>
<thead>
<tr>
<th>Class</th>
<th>Roller (3/8&quot;)</th>
<th>BP-80</th>
<th>Revolution</th>
<th>RotaFlow</th>
<th>CardioHelp</th>
<th>DeltaStream</th>
<th>CentriMag</th>
<th>PediMag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime (mL)</td>
<td>22 (per ft)</td>
<td>$150</td>
<td>$150</td>
<td>$200</td>
<td>$12K</td>
<td>NA</td>
<td>$8.5K</td>
<td>$6.5K</td>
</tr>
<tr>
<td>Cost</td>
<td>$100</td>
<td>$150</td>
<td>$150</td>
<td>$200</td>
<td>$12K</td>
<td>NA</td>
<td>$8.5K</td>
<td>$6.5K</td>
</tr>
<tr>
<td>Max RPM</td>
<td>250</td>
<td>4,400</td>
<td>3,500</td>
<td>5,000</td>
<td>5,000</td>
<td>10,000</td>
<td>5,500</td>
<td>5,500</td>
</tr>
<tr>
<td>Max Flow (L/min)</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>10</td>
<td>1.7</td>
</tr>
<tr>
<td>Max Outlet Pressure (mmHg)</td>
<td>NA</td>
<td>900</td>
<td>800</td>
<td>750</td>
<td>NA</td>
<td>550</td>
<td>600</td>
<td>540</td>
</tr>
<tr>
<td>NIH (g/100L)</td>
<td>0.029</td>
<td>0.061</td>
<td>0.034</td>
<td>0.033</td>
<td>NA</td>
<td>NA</td>
<td>0.003</td>
<td>0.015</td>
</tr>
</tbody>
</table>

**ONLY ¼” Centrifugal Pump**
Patient Outcomes by Pump Type
Roller vs. Centrifugal

• Review of ELSO database 2007-2009
• Propensity score matching of pts who were more likely to receive a centrifugal pump based on pre-ECMO variables
• Pts receiving centrifugal pumps were:
  ▪ Less likely to survive: OR=0.6 (0.3-1.1)
  ▪ More likely to have hemolysis OR 7.7 (2.8-21.2)
    • More likely have hypertension: OR 3.2 (1.3-8)
    • More likely to have acute renal failure: OR 2.4 (1.1-5.6)
• CAUTION: Data from era prior to adoption and proper use of newer centrifugal technology
  ▪ Over 50% of centrifugal pumps were old technology (Biomedicus)

Patient Outcomes by Pump Type
Roller vs. Centrifugal

• An updated single-center report on the change from roller pumps with polypropelene oxygenators, venous reservoirs and hemoconcentrators to streamlined, mag-lev centrifugal pumps and polymethylpentene oxygenators found

  ▪ Increasing plasma hemoglobin with time in the older systems
  ▪ Fewer mechanical issues in the newer system
  ▪ Fewer clots and fibrin build-up in newer system

Pump Conclusions

• “Modern” centrifugal pumps likely afford improved biocompatibility for the patient. As yet this has not been demonstrated, in a scientific fashion, to lead to improved outcomes in terms of survival.

• Connection size presents a problem for smaller patients (ie 3/8” → ¼”)

• Roller pumps remain an inexpensive and effective means for short term ECMO. Occlusion setting is important
Better Oxygenators

- Switch to hollow fiber membrane oxygenators from silicone membrane oxygenators and from polypropylene to polymethylpentene
  - Superior gas exchange
  - Decreased resistance ➔ centrifugal pumps
  - Decreased prime
  - Decreased RBC, platelet and plasma consumption / damage
Membrane Structure
MICRO POROUS POLYPROPYLENE HOLLOW FIBERS

Microporous membrane pore size max. <0.2 μm

7000 nm

0.12 nm

blood path

gas path

PMP Membrane pore size max = 0 μm

7000 nm

blood path

gas path

Water Vapor
MICRO POROUS POLYPROPYLENE HOLLOW FIBERS
Polypropylene Membrane Structure
Polymethylpentene Diffusion Membrane Structure
# Current Generation PMP Oxygenators

<table>
<thead>
<tr>
<th></th>
<th>CardioHelp HLS 7.0</th>
<th>Quadrox Adult</th>
<th>Quadrox Peds</th>
<th>Hilite 800 LT</th>
<th>Hilite 2400LT</th>
<th>Hilite 7000LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Range (L/min)</td>
<td>0.5-7</td>
<td>0.5-7</td>
<td>0.2-2.8</td>
<td>0.1-0.8</td>
<td>0.4-2.4</td>
<td>1-7</td>
</tr>
<tr>
<td>Area</td>
<td>1.8</td>
<td>1.8</td>
<td>0.8</td>
<td>0.32</td>
<td>0.65</td>
<td>1.9</td>
</tr>
<tr>
<td>Priming Vol</td>
<td>273</td>
<td>215</td>
<td>81</td>
<td>55</td>
<td>95</td>
<td>275</td>
</tr>
<tr>
<td>Coatings Available</td>
<td>Hep, Polymer</td>
<td>Alb, Hep, Polymer</td>
<td>Alb, Hep, Polymer</td>
<td>Rheoparin</td>
<td>Rheoparin</td>
<td>Rheoparin</td>
</tr>
<tr>
<td>Pressure Drop</td>
<td>50</td>
<td>70</td>
<td>38</td>
<td>58</td>
<td>160</td>
<td>185</td>
</tr>
<tr>
<td>Oxygen Transfer</td>
<td>725</td>
<td>425</td>
<td>180</td>
<td>52</td>
<td>149</td>
<td>410</td>
</tr>
</tbody>
</table>
PMP Oxygenators Last Longer

- Single Center
- Adult Postcardiotomy Shock
  - Biopump + Affinity (PP) oxy N=11
  - Biopump + Quadrox (PMP) oxy N=11
  - Rotaflow + Quadrox (PMP) oxy N=27
- No change in survival or hospital outcomes
- No change in stroke or bleeding rates
- Only effect was in lifespan of oxygenator system.

**Figure 2.** Percentage of oxygenators exchanged during period of ECMO support. Nearly 70% of oxygenator exchanges occurred in Gp 1 patients. There were no oxygenators exchanged in Gp 2 patients and only a small number exchanged in Gp 3. Gp = Group; Bio = Biomedicus centrifugal pump; QD = Quadrox D oxygenator; *p = 0.04.

Oxygenator Conclusions

• Newer oxygenators offer superior hemodynamic performance in terms of resistance
• Virtually no plasma leakage which leads to fewer changes and better longevity
• Likely to improve outcomes
Other Circuit Considerations

• Bladder vs Servo Regulation?
• Saturation Monitoring
  ▪ NIRS
• Pressure Monitoring
• Coatings
• Access Points to Circuit
• Hemofilters

* Simplicity vs Complexity as it relates to Safety
Maybe its our management that leads to undesirable outcomes?

- Anticoagulation
- Intubation
- Paralytics
- NPO
- Complete bed rest
- Ventilator Management
- Failure to do weaning trials
What are the goals of ECMO?

- Oxygen Delivery for cellular respiration
- CO2 removal
- Heart Decompression
- Lung Protection
- Venous Drainage
- Reversal of Acidosis
- Weaning of Inotropes
- Protection from complications
  - Bleeding / Thrombosis
  - Neurologic Injury
What are the goals of ECMO?

- Getting Off of ECMO!
  - Identification and Correction of Anatomic or Physiologic Problems
    - ECHO
    - Catheterization
    - Surgical Revision
    - Transition to Ventricular Assist Device if Recovery Not Anticipated
Management of Anti-coagulation on ECMO

• Maintaining the delicate balance between hemostasis and bleeding is not easy!
Maybe It’s Our Anticoagulation?

Figure 2: Comparison of the number of red blood cell (RBC) units transfused during extracorporeal membrane oxygenation (ECMO) procedures between survivors and non-survivors in different types of ECMO: VA ECMO, veno-arterial ECMO, W ECMO, veno-venous ECMO.

Factors associated with outcomes of patients on extracorporeal membrane oxygenation support: a 5-year cohort study

Cecile Aubron1,4, Allen C. Cheng2,5, David Plancher1,6, Tim Leong1,6, Geoff Magrin3, D. Jamie Cooper1,4, Carlos Scheinin2,6 and Vince Pelegro1,4

Children’s Hospital of Pittsburgh of UPMC
Maybe Its Our Anticoagulation

• Bleeding is most common and most lethal complication of ECMO
• ACT is “binary” test
• Designed for maximal anticoagulation
• All tests our dependent upon the procoagulant used
• Poor correlation between ACT and PTT and ACT and heparin dose
• Anti Xa increasing in usage ➔ measures heparin concentration not anticoagulation
ECMO Management by aPTT

<table>
<thead>
<tr>
<th>PTT-Managed</th>
<th>Odds Ratio</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO Survival</td>
<td>1.1</td>
<td>0.3-4.0</td>
<td>NS</td>
</tr>
<tr>
<td>Survival to Discharge</td>
<td>0.85</td>
<td>0.31-2.3</td>
<td>NS</td>
</tr>
<tr>
<td>Bleeding Complication</td>
<td>0.11</td>
<td>0.02-0.51</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Clotting Complication</td>
<td>3.02</td>
<td>1.1-8.5</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ACT-Managed (N=47)</th>
<th>aPTT-Managed (N=28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>1.86 ± 4.7</td>
<td>0.7 ± 1.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>8.7 ± 13.9</td>
<td>4.5 ± 5.2</td>
</tr>
<tr>
<td>Time (hrs)</td>
<td>158 ± 159</td>
<td>131 ± 206</td>
</tr>
<tr>
<td>ACT or ACT-LR (sec)</td>
<td>141 ± 28</td>
<td>200 ± 34</td>
</tr>
<tr>
<td>POC aPTT (sec)</td>
<td>110 ± 80**</td>
<td>75 ± 34**</td>
</tr>
<tr>
<td>Lab aPTT (sec)</td>
<td>95 ± 42**</td>
<td>76 ± 29**</td>
</tr>
<tr>
<td>Platelets (x1,000/μL)</td>
<td>109 ± 48</td>
<td>111 ± 34**</td>
</tr>
<tr>
<td>Fibrinogen (mg/dL)</td>
<td>206 ± 143**</td>
<td>242 ± 109**</td>
</tr>
<tr>
<td>Heparin Dose (IU/kg/hr)</td>
<td>34 ± 21**</td>
<td>23 ± 12**</td>
</tr>
</tbody>
</table>

## Testing Summary

- Each assay comes with inherent set of advantages/disadvantages!

<table>
<thead>
<tr>
<th>Intended to Monitor</th>
<th>ACT+</th>
<th>ACT-LR</th>
<th>PTT</th>
<th>TEG</th>
<th>Anti-Xa</th>
<th>ATIII</th>
<th>D-Dimer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate-high heparin dose (1-6 IU/mL)</td>
<td>Low-moderate heparin dose (0-2.5 IU/mL)</td>
<td>Low heparin dose (0-1.5 IU/mL)</td>
<td>Low heparin dose (0-1.5 IU/mL)</td>
<td>UFH and LMWH</td>
<td>UFH and LMWH</td>
<td>Fibrinolysis</td>
<td></td>
</tr>
<tr>
<td><strong>Used in</strong></td>
<td><strong>CPB</strong></td>
<td><strong>ECMO</strong></td>
<td><strong>ECMO &amp; VAD</strong></td>
<td><strong>ECMO &amp; VAD</strong></td>
<td><strong>ECMO &amp; VAD</strong></td>
<td><strong>ECMO &amp; VAD</strong></td>
<td><strong>ECMO &amp; VAD</strong></td>
</tr>
<tr>
<td><strong>Test Kit</strong></td>
<td>silica, kaolin, phospholipid</td>
<td>Lower conc. silica, kaolin, phospholipid</td>
<td>Glass, kaolin, phospholipid</td>
<td>Kaolin and Calcium</td>
<td>Excess FXa Colorimetric Assay</td>
<td>ELISA</td>
<td>ELISA</td>
</tr>
</tbody>
</table>

---

Children’s Hospital of Pittsburgh of UPMC

Heart Institute
How We Do It

• For ECMO, the following are generally considered our “norms” for anticoagulation:
  • Start heparin after ECMO initiation: 10 IU/kg/hr
  • ACT: 180-220 sec
  • aPTT: 80-100 sec
  • Anti-Xa: 0.3-0.6 U/ml
  • AT III: >60%
  • Platelets: > 80 x 10⁹/L
  • Fibrinogen: >150 mg/dL
Our Anticoagulation Testing

- **Hourly POC testing**
  - ACT-LR
    - Whole blood tests to trend interaction b/w platelets and heparin
  - Can be used to trigger a lab aPTT check

- **Less frequent testing**
  - aPTT q4hr
    - Drives heparin dose changes
  - Anti-Xa, ATIII, and TEG q12-24 hr
    - Gives a snapshot of patient heparin dose, and underlying clotting cascade
  - Plt and fibrinogen q8hr
    - Provides treatment points for important parts of the coagulation cascade and interpretation of POC and lab tests
Short- and intermediate-term survival after extracorporeal membrane oxygenation in children with cardiac disease

Constantinos Chrysostomou, MD, Victor O. Morell, MD, Bradley A. Kuch, BS, RRT-NPS, FAARC, Elizabeth O’Malley, CCP, LP, Ricardo Munoz, MD, and Peter D. Wearden, MD

Methods

• A retrospective single-center study evaluating the outcome and predictors of mortality in children with heart disease treated with ECMO from January 2006 – January 2010.
  – N = 98
  – Dedicated Pediatric CICU
  – Surgical and Non-Surgical Population
| **Children’s Hospital of Pittsburgh 2006-2010 Cardiac ECMO**  
<table>
<thead>
<tr>
<th><strong>Baseline Characteristics: Population n = 98</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median</strong></td>
</tr>
<tr>
<td>Age (Months)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Male Gender</td>
</tr>
<tr>
<td>Repair Congenital Heart Defect</td>
</tr>
<tr>
<td>Basic Aristotle Score</td>
</tr>
<tr>
<td>ECLS Initiation in Operating Room</td>
</tr>
<tr>
<td>Chest Cannulation</td>
</tr>
<tr>
<td>Cardiac Arrest Prior to Cannulation</td>
</tr>
<tr>
<td>ECMO Complications</td>
</tr>
<tr>
<td>Duration of ECMO Support (Hours)</td>
</tr>
</tbody>
</table>
## Baseline Characteristics: ECMO Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Median</th>
<th>Interquartile range (25% – 75%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO Flow 4 Hours (mL/kg/min)</td>
<td>133.0</td>
<td>101.8 – 160.0</td>
</tr>
<tr>
<td>ECMO Flow 24 Hours (mL/kg/min)</td>
<td>130.1</td>
<td>95.2 – 163.3</td>
</tr>
<tr>
<td>Plasmapheresis</td>
<td>17 (17.2%)</td>
<td></td>
</tr>
<tr>
<td>Lowest pH &lt;6 Hour of Support</td>
<td>7.47</td>
<td>7.32 – 7.55</td>
</tr>
<tr>
<td>Highest Lactate &lt;6 Hours of Support</td>
<td>3.2</td>
<td>2.10 – 4.45</td>
</tr>
<tr>
<td>Epinephrine dose Separation ECLS (mcg/kg/min)</td>
<td>0.08</td>
<td>0.09 – 0.15</td>
</tr>
<tr>
<td>PEEP first 24 hours of ECLS (cmH₂O)</td>
<td>8.0</td>
<td>6.0 – 10.0</td>
</tr>
<tr>
<td>ECMO Complications</td>
<td>45 (45.9%)</td>
<td></td>
</tr>
<tr>
<td>Duration of ECMO Support (Hours)</td>
<td>65</td>
<td>32 - 113</td>
</tr>
</tbody>
</table>
Recovery & Survival

28 day Survival – 78 %
Hospital Survival – 76%
ECPR Survival - 75%

N = 98 (102 runs)

Avg Duration 65 hours (32-113)
No Difference in Mortality by ECMO Initiation Location

- Operating Room: 20.7% (p = 0.3)
- ECPR: 29.3% (p = 0.27)
- CICU: 39.3% (p = 0.11)
## Baseline Characteristics: Survivors vs. Non-Survivors

<table>
<thead>
<tr>
<th></th>
<th>Survivors (n= 69)</th>
<th>Non-Survivors (n=29)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong> (Months)</td>
<td>0.9 [0.25 – 14.7]</td>
<td>1.52 [0.161 – 8.17]</td>
<td>0.723</td>
</tr>
<tr>
<td><strong>Weight</strong> (kg)</td>
<td>3.6 [3.0 – 8.38]</td>
<td>3.0 [2.5 – 6.60]</td>
<td>0.176</td>
</tr>
<tr>
<td>Male Gender</td>
<td>42 (60.9%)</td>
<td>16 (57.1)</td>
<td>0.453</td>
</tr>
<tr>
<td>Chest Cannulation</td>
<td>42 (60.9%)</td>
<td>15 (53.6%)</td>
<td>0.503</td>
</tr>
<tr>
<td>Cardiac Arrest Prior to Cannulation</td>
<td>27 (39.1%)</td>
<td>14 (50.0%)</td>
<td>0.225</td>
</tr>
<tr>
<td>Repair Congenital Heart Defect</td>
<td>35 (50.7%)</td>
<td>13 (46.3%)</td>
<td>0.701</td>
</tr>
<tr>
<td><strong>Basic Aristotle Score</strong></td>
<td>10.0 [7.63 – 14.0]</td>
<td>10.0 [9.30 – 14.0]</td>
<td>0.425</td>
</tr>
<tr>
<td><strong>Duration of ECMO Support</strong> (hours)</td>
<td>56.0 [24.8 – 86.0]</td>
<td>113.0 [29.8 – 86.0]</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
## Distribution of ECMO Complications

(n=45; 45.6% of population)

<table>
<thead>
<tr>
<th>Complication</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleeding</td>
<td>21 (46.7%)</td>
</tr>
<tr>
<td>Hemofiltration</td>
<td>16 (35.6%)</td>
</tr>
<tr>
<td>Inotropic Support During ECMO</td>
<td>13 (28.3%)</td>
</tr>
<tr>
<td>Clot Formation</td>
<td>12 (26.7%)</td>
</tr>
<tr>
<td>Oxygenator Failure</td>
<td>8 (17.8%)</td>
</tr>
<tr>
<td>Neurologic Complication</td>
<td>7 (15.6%)</td>
</tr>
<tr>
<td>Cardiac Arrhythmias</td>
<td>4 (8.9%)</td>
</tr>
</tbody>
</table>

Groups are not mutually exclusive
Use of Plasma Exchange on ECMO

MPELOD* after PLEX start

Unpublished data.
*Modified PELOD score. Mean, +/- 95% CI
Children’s Hospital of Pittsburgh Post Transplant ECMO Data 2010-2015

• 12 Patients placed on ECMO following Heart Transplant
  ▪ 7 (58%) were failure to wean from bypass during transplant procedure itself (immediate graft dysfunction)
  ▪ 5 (42%) were post Tx cardiac failure
    • 2 were < 1 month from transplant
    • Average time since Tx was 3.9 years
Outcomes

- Failure to wean bypass after Tx
  - 6/7 weaned from ECMO
  - 1/7 weaned to a VAD
    - Patient subsequently re-transplanted without complication

- Post Tx Rejection/Cardiac Failure
  - 4/5 weaned from ECMO
  - 1/5 weaned to VAD
    - Subsequently re-transplanted

- 100% survival
Beginning to See Improvement in Long Term Support
Delineating Survival Outcomes in Children <10 kg Bridged to Transplant or Recovery With the Berlin Heart EXCOR Ventricular Assist Device

83.2% vs 56.7% “successful” outcome p <0.001

56.7% vs 27.3% “successful” outcome p <0.001
Case Long Term ECMO

- Healthy 17 yo F athlete
- Admitted with fever and myalgia
- Intubated hospital day 2
- V/V ECMO day 5
- Worsening right heart failure
- VA ECMO 3 days later
- Lung Bx → necrotizing pneumonia
- ECMO day 22 → extubated
- Circuit changes ECMO day 17, 28 and 40
- Double Lung Transplant ECMO day 55
Case Long Term ECMO

- Healthy 17 yo F athlete
- Admitted with fever and myalgia
- Intubated hospital day 2
- V/V ECMO day 5
- Worsening right heart failure
- VA ECMO 3 days later
- Lung Bx → necrotizing pneumonia
- ECMO day 22 → extubated
- Circuit changes ECMO day 17, 28 and 40
- Double Lung Transplant ECMO day 55
- Discharge to home post transplant day #30
Conclusions

- ECMO has vastly improved in the last decade and has an increasingly important role in our armamentarium
  - Better pumps
  - Better oxygenators
  - Used earlier
    - Before arrest
    - Before significant acidosis
    - Before massive inotropes
    - Before lung injury
  - Improving management and anticoagulation
Conclusions

- ECMO has a particular place in:
  - Post Cardiotomy Support
  - ECPR
  - Pulmonary Support
  - Children < than 5 kg
  - Congenital Heart Disease
  - Bridge to Decision in the face of:
    - Myocarditis
    - Cardiac arrest
    - Pulmonary dysfunction
    - End Organ dysfunction
    - Neurologic Injury