ECMO in Adult Critical Care

William R. Lynch, M.D.
Associate Professor
Department of Cardiothoracic Surgery
University of Iowa
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Disclosures

• No Relevant Financial Interests to Report
• Products discussed for patient use are FDA approved
• Some products discussed are used “off label”
Learning Objectives

• History of ECMO
• Appreciation of modern ECMO technology and implications in adult critical care
• Discuss future evolution and possibilities of extracorporeal technology in adult critical care
Definitions

• ECMO
  – ExtraCorporeal Membrane Oxygenation

• ECLS
  – ExtraCorporeal Life Support
Extracorporeal Life Support (ECLS, ECMO)

Support of heart or lung function with mechanical devices which:

- is temporary (days to weeks)
- can be partial or total
- avoids ongoing iatrogenic injury
- and sustains life while bridging to organ recovery or replacement.
ECMO and Cardiopulmonary Bypass
Early Cardiopulmonary Bypass

- Access
- Anticoagulation
- Venous Reservoir
- Temperature control
- Pump
- Gas exchange device
- 50% mortality
  - Low cardiac output
  - Oliguria
  - Acidosis
  - Respiratory failure
  - Fatal when supported for longer than 1 hour
Membranes
Four Day Partial Bypass in Dogs

Five Days of ECC in Animal Model

Bartlett: and Gazzaniga
5 day ECC in animals, 1971
First ECMO case

First Pediatric Cardiac Support

- 3 year old
- Post cardiotomy stun after Mustard
- Gazzaniga and Bartlett, 1972
First Pediatric Cardiac Support

- 3 year old
- Post cardiotomy stun after Mustard
- Gazzaniga and Bartlett, 1972
The first neonatal ECMO survivor

Esperanza 1975

Esperanza 1996
CPB and ECMO

- **Similarities**
  - Access
  - Pump
  - Heparin
  - Oxygenator
  - Temperature Control

- **Differences**
  - Pulmonary blood flow
  - ACTs 140-220 sec
  - No reservoir
  - Extrathoracic cannulation
ECMO Evolves

- 1976- ASAIO: 9 neonates, 3 survivors
- 1977- JTCVS: 16 neonates, 6 survivors
- 1979- Programs start at MCV & Pittsburgh
- 1979 – NIH-ARDS ECMO Trial (Zapol)
- 1985-90 – Neonatal ECMO trials
- 1986 – 18 centers, 500 cases
- 1990 – Standard practice for neonates and peds
- 2000 – Standard practice for adults in some centers
- 2001- 2007 – UK clinical PRCs in neonates and adults
- 2011 – 141 centers, 41,000 cases
## ELSO Registry
### Overall Patient Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Surv ECLS</th>
<th>Surv to DC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neonatal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>24,344</td>
<td>20,608</td>
<td>18,276</td>
</tr>
<tr>
<td>Cardiac</td>
<td>4,232</td>
<td>2,566</td>
<td>1,663</td>
</tr>
<tr>
<td>ECPR</td>
<td>640</td>
<td>403</td>
<td>245</td>
</tr>
<tr>
<td><strong>Pediatric</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>4,771</td>
<td>3,094</td>
<td>2,656</td>
</tr>
<tr>
<td>Cardiac</td>
<td>5,221</td>
<td>3,322</td>
<td>2,502</td>
</tr>
<tr>
<td>ECPR</td>
<td>1,220</td>
<td>646</td>
<td>479</td>
</tr>
<tr>
<td><strong>Adult</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory</td>
<td>2,340</td>
<td>1,474</td>
<td>1,261</td>
</tr>
<tr>
<td>Cardiac</td>
<td>1,540</td>
<td>812</td>
<td>598</td>
</tr>
<tr>
<td>ECPR</td>
<td>516</td>
<td>201</td>
<td>153</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>44,824</td>
<td>33,126</td>
<td>27,833</td>
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</tbody>
</table>

- Surv ECLS: Survival to Extracorporeal Life Support
- Surv to DC: Survival to Discharge
ELSO Centers
ELSO Registry

Runs per year

- Card (16 years and over)
- Card (1 year < 16 years)
- Card (31 days < 1 year)
- Card (0 - 30 days)
- Adult Pulm
- Ped Pulm
- Neo Pulm
ELSO Registry
Neonatal Respiratory Runs
ELSO Registry
Adult Respiratory Cases
ELSO Registry
Cardiac Cases by Year: Under 16

![Graph showing annual and cumulative cases from 1988 to 2010. The number of cases increases over time, with a sharp rise towards the end of the period. The cumulative cases are also plotted on the right axis.]
ELSO Registry
Cardiac Cases by Year: 16 and Over
CESAR
(Conventional ventilation or ECMO for Severe ARDs)

• Inclusion
  – 18-65 years
  – Severe but potentially reversible respiratory failure
  – Murray score ≥ 3.0 or
  – Uncompensated hypercapnoea with pH < 7.20

• Exclusion
  – High pressure and/or high FiO2 > 7 days
  – Intra cranial bleeding
  – Contra-indication to anticoagulation
  – Moribund

UK Adult ECMO Study
CESAR. Peek and Firmin 2000-2006

180 ARDS Pts, 30 centers

Consent

Randomize

90 Conventional
47% Survival

90 Optimal+ECMO
63% Survival
CESAR
Prospective Randomized Trial, 2008

Kaplan-Meier survival estimates, by allocation

Analysis time (days)

- Conventional
- ECMO
CESAR

• Best Standard Practice vs Protocol
• Why the difference?
  – Referral Center
  – Protocol
  – Inability to achieve protective ventilation
  – ECLS
  – Cardiothoracic Surgeons
ECLS in 2005

- It works, BUT
- Complex
- Specialist required
- System failures
- Thrombogenic
- Vascular access can be difficult
- Smart people don’t understand the physiology
- (Why are they still BLUE??)
Adult ECMO 2005

• Indications
  – Acute severe heart and/or lung failure
  – Considered at 50% mortality risk
  – Indicated at 80% mortality risk

• Contraindications
  – Relative
  – Conditions incompatible with normal life
  – Pre-existing conditions affecting quality of life
  – Age
  – Size
  – Futility
Patient Selection in 2005

- 65 yrs or less
- 7 days of ventilation or less
- PaO2/FiO2 < 100
- Compliance < 0.5 cc/cmH2O/kg
- No neurologic injury
- Pulm Art Pressures < 2/3 systemic
- No bleeding contraindications
ECLS 2010
Technical Improvements

- Oxygenator with PMP
- Centrifugal pumps
- Cannulaes
ECMO Technology 2011
“how it looks”

- New low resistance lungs can be used with low pressure safe pumps, are less thrombogenic,

- Inherently safe, self regulating circuit needs only a flow switch

- Safe easy vascular access

- The physiology will teach itself
Are ICU’s bad?

1 day ventilation
6 days VV ECMO
11 day hospital stay
Fully recovered

12 day ventilation
34 days ECMO
124 day hospital stay
Still recovering
15 consecutive Adult Respiratory ECMO

15 VV ECMO

Extubated
- 10 (67%)
  - Re-intubated
    - 5
      - Trache
        - 3
          - Survived
            - 2
            - No Trache
              - 2
              - Survived
              - 0

  - Remained Extubated
    - 5

Intubated
- 5 (33%)
  - No Trache
    - 4
      - Survived
      - 1
  - Trache
    - 1
      - Survived
      - 1

Total Survival: 9/15 (60%)  Extubated Survival: 7/10 (70%)
Patient Selection in 2011

• 75 yrs or less?
• Hypoxia refractory to mechanical ventilation
  – FiO2 > 70%
  – PEEP > 15
  – PaO2/FiO2 < 300
  – Within 6-12 hours
• No neurologic injury
• No bleeding contraindications
ECLS in a Surgical Practice 2011

- Respiratory Failure
- Cardiac Failure
- Donation after Cardiac Death
  - EISOR (Extracorporeal Interval Support for Organ Retrieval)
- Hypothermia
  - Trauma resuscitation
  - Cold water drownings
- ECPR
  - Massive PE
- Hypercarbia
- Sepsis
- Drug overdose
ECLS Research at University of Iowa

• Consider ECLS for Lung Transplantation
  – Recipient Support
    • Cystic Fibrosis
    • Interstitial Pulmonary Fibrosis
    • Pulmonary hypertension
  – Donor Support
    • Donation after Cardiac Death/DCD
  – Organ Support
    • Resuscitation
    • Reconditioning
    • Evaluation
ECLS without the Patient

Donor lung evaluation
Subjective Donor Evaluation

<table>
<thead>
<tr>
<th>Box 1</th>
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<tbody>
<tr>
<td><strong>Standard International Society for Heart and Lung Transplantation donor lung criteria</strong></td>
</tr>
</tbody>
</table>

- Age <55 years
- Clear serial chest radiograph
- Normal gas exchange ($P_{aO_2} > 300$ mm Hg on $F_{iO_2} = 1.0$, positive end-expiratory pressure [PEEP] 5 cm $H_2O$)
- Absence of chest trauma
- No evidence of aspiration or sepsis
- Absence of purulent secretions at bronchoscopy
- Absence of organisms on sputum Gram’s stain
- No history of primary pulmonary disease or active pulmonary infection
- Tobacco history <20 pack years
- ABO blood-group compatibility
- Appropriate size match with prospective recipient

Objective Donor Evaluation

• Function as described by
  – Pulmonary Compliance
    • Static Compliance as measured by ventilator
  – Pulmonary Hemodynamics
    • Pulmonary and Left Atrial Pressure
    • Cardiac Output
    • Pulmonary Vascular Resistance
  – Regional Perfusion
    • MDCT Volumetric Spiral Scan
    • MDCT Perfusion Imaging Techniques

• Anatomy as described by
  – 3 dimensional MDCT reconstruction
Animal Model

- Sheep (30 - 40 kg)
- Heart/Lung block removed using transplant techniques and cooled to 4º C
- Heart cannulated and organs perfused
- Slowly re-warmed then ventilated
- Goal “Cardiac Output”
  - 60-75 cc/kg/min
- Goal Minute Ventilation
  - 80 - 100 cc/kg/min
- 2 hour duration

- PA and LA pressures measured
- PAP limited to < 20 mmHg
- Mechanical ventilation: PCV with PIP < 30 cm H₂O, PEEP of 5 cm H₂O
- Compliance Calculated
- Pulmonary Vascular Resistance Calculated
Imaging Protocol

- Siemens Sensation 64 MDCT scanner
- Volumetric spiral scans
  - every 20 minutes for 2 hours
  - constant PEEP breath-hold of 25 cm H₂O
- Perfusion imaging
  - performed at 120 minutes
  - contrast injection of 0.5 cc/kg over two seconds.
  - Perfusion data acquired at 2, 3, 4, and 5 L/min
Schematic drawing of lung assessment ex vivo
From Steen’s Solution Brochure, Vitrolife
Function
Pulmonary Compliance

- Compliance
  - 52 - 68 cc/cmH2O
- Tidal Volume
  - 6 - 12 cc/kg
Function

Pulmonary Hemodynamics

Graphs showing pressure and PVR (Pulmonary Vascular Resistance) over time.
Function

Pulmonary Blood Flow and Minute Ventilation

[Graph showing flow rate over time]
Function
Regional Perfusion Over Time

Volumetric Data Analysis
Function

Regional Perfusion Over Time

Quantitative Image Analysis at TLC
Function
Regional Perfusion Related to Flow Rate

Perfusion Imaging
Function
Regional Perfusion Related to Flow Rate

Color Map of Pulmonary Blood Flow
Anatomy
3 Dimensional Reconstruction
Perspective

My first ECLS patient
Summary

- ECMO (as ICU’s, ventilators, dialysis,..) has evolved in 40 years
- Technology has advanced in 40 years (ICU, vent, …)
- ECMO systems have evolved so that they can “stand alone” at the bedside (CVVH)
- The decision to use ECMO is a risk/benefit analysis compared with alternatives
- As the safety profile (and simplicity profile) evolves, the opportunity for ECMO will expand.
- In less than 5 years, the strategy of ECMO has changed so that it is practical and safe to have patients awake and walking
ECMO

Learn to think differently
Thank you

EXTRACORPOREAL LIFE SUPPORT

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