ECMO: Is a 4-letter word

Objectives
- Review current practice for Extracorporeal Life Support devices
- Discuss relevant physiology for Extracorporeal Membrane Oxygenation
- Highlight difficulty of patient selection using evidence from medical literature

Disclosures
No financial disclosures. However this presentation contains discussion of a pharmaceutical or medical device for which FDA has not granted approval. I agree to disclose to the audience whether the pharmaceutical or medical device is classified by the FDA as “investigational” or “off-label” with respect to the intended use.
Case:
2 year-old male who developed severe ARDS after scald burn

Case:
- 2 year-old male, 13.5 kg presenting to PICU after developing compartment syndrome with scald burn to bilateral feet
- HFOV: 4 Hz, 60 Amp, 38-39 MAP, 100% O₂
- ABG: 7.468 / 19.7 / <45 / -7
- Vasoactives: norepinephrine
- ECMO VA cannulation

Objectives
- Describe physiology of lung injury
- Discuss difference VV versus VA
- Extracorporeal Membrane Oxygenation
- Highlight ECMO cases and lung rest

Open Lung Ventilation Strategy: PEEP
Fraese, CCM, 1997
Capillary Leak

- Electron microscopy demonstrates the disruption of the alveolar-capillary membrane secondary to mechanical ventilation with lung distention.
- Note the leakage of RBCs and other material into the alveolar space.

Fu Z, JAP, 1992; 73:123

Lung protection improves mortality

- 861 patients, p=0.007
  
<table>
<thead>
<tr>
<th>Protected</th>
<th>Unprotected</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV 6 mL/kg, PIP &lt; 30</td>
<td>TV 12 mL/kg, PIP &lt; 50</td>
</tr>
<tr>
<td>31% mortality</td>
<td>40% mortality</td>
</tr>
</tbody>
</table>
- Study halted early due to mortality difference

ARDSNet, NEJM 2000.

High Frequency Ventilation

  - Canada
  - Interim analysis of 275 patients HFOV vs 273 control
  - In hospital mortality: 47% vs 35%
    - RR: 1.33; 95% CI, 1.09 to 1.64; P = 0.005
  - UK
  - Analysis: 166 patients HFOV vs 163 conventional
  - No difference

Kaplan-Meier Survival Curves

Role of ECMO: theory

- Allow lung rest and avoids baro-, volu-, stretch trauma.
- Maintains oxygenation and ventilation.
- Done with or without cardiac output support.
- Allows time for the rest of the body to heal, treatments to take effect, and underlying disease process to resolve.

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ECMO Schematic

- ECMO
  - Veno-venous (VV)
  - Veno-arterial (VA)
  - Hybrid
- VAD (left, right, biventricular)
- ECCO₂R
- ECPR
CANNULA SIZE

- Poiseuille’s Law: $F = \frac{P \pi r^4}{8Lv}$
  - $F$ = flow; $P$ = pressure; $r$ = radius; $L$ = length; $v$ = viscosity

  So, a WIDE ($r^4$) and SHORT ($L$) catheter and circuit allow for best FLOW ($F$)

Tubing Size

- Blood flow through 1 meter of tubing at 100mmHg pressure gradient for each internal diameter:

<table>
<thead>
<tr>
<th>Blood Flow (L/min) at 100mmHg</th>
<th>Internal Diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>3/16</td>
</tr>
<tr>
<td>2.5</td>
<td>1/4</td>
</tr>
<tr>
<td>5.0</td>
<td>3/8 Neonatal</td>
</tr>
<tr>
<td>10.0</td>
<td>1/2</td>
</tr>
</tbody>
</table>

Veno-Arterial (VA) ECMO Circuit

ECMO Circuit is in parallel to native pulmonary and coronary circulation

Veno-Venous (VV) ECMO Circuit

ECMO Circuit is in series with the native pulmonary and coronary circulation

ECMO Schematic

Dialed Flow vs. Effective Flow

Why recirculation matters!
Gas Exchange

- Ventilation:
  - Carbon dioxide removal
- Oxygenation:
  - Hemoglobin, saturation, dissolved
  - Cardiac output
  - Consumption

Oxygen Delivery (DO₂)

\[ \text{DO₂} = \text{Arterial O₂ Content} \times \text{Cardiac Output} \]

Arterial Oxygen Content

\[
\text{CaO₂} = (1.36 \times \text{Hbg} \times \text{SaO₂}) + (0.003 \times \text{PaO₂})
\]

- Hemoglobin concentration (mg/dL)
- % hemoglobin saturated with O₂ (O₂ sat)
- Arterial PO₂ (PaO₂)

\[
\text{CaO₂} = (1.36 \times 15 \times 100\%) + (0.003 \times 100)
\]

\[
\text{CaO₂} = (20.4) + (0.3) = 20.7 \text{ ml O₂/dL}
\]

Hemoglobin

- Made of 4 protein chains with Iron (Fe)
- “Cooperative binding”

Cardiac Output

\[
\text{Cardiac Output on ECMO} = [\text{Native Cardiac Output} + \text{ECMO Blood Flow}]
\]

Example: 100 ml/kg/min + 100 ml/kg/min
Coagulation Cascade + ECMO Circuit = A Complex System

Sepsis & Coagulation

Blood-Surface Interactions
- Tubing & Artificial Surfaces
  - Uncoated
  - Coated: Bioline • Heparin bonded
- Platelets
  - White clots
  - Red clots

Heparin Basics - ECMO
- Initial bolus 50 units/kg
- Heparin drip titrated to effect by perfusion
- Normal drip rate = 25-60 units/kg/hr

Heparin Monitoring
- Activated clotting time (ACT)
  - Point-of-care testing
  - Measures whole blood
  - Time to clot formation measured in seconds
  - Normal: 90-120
  - Context matters
- Activated partial thromboplastin time
  - Aim for 1.5-2× control
  - Heparin Antifactor Xa level
  - Thromboelastogram

ECMO = prolonged, low-grade, consumptive coagulopathy
Objectives

• Review current practice for Extracorporeal Life Support devices
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Primary Hypotheses

• For patients with severe but potentially reversible respiratory failure, ECMO:
  – Will increase the rate of survival without severe disability by six months post randomization.
  – Will be cost effective, compared to conventional ventilatory support.

Inclusion Criteria

• Potentially reversible respiratory failure
• Age 18-65 years
• Murray score > 3.0
• Hypercapnea with pH < 7.20
• Duration of high pressure and high FiO₂ ventilation < 7 days
• No contraindication to limited heparinisation
• No contraindication to continuation of active treatment

Murray score

• P/F ratio: On FiO₂ 1.0
  – > 300=0, 225-299=1, 175-224=2, 100-174=3, < 100=4
• CXR
  – normal=0, 1 point per quadrant infiltrated
• PEEP
  – < 5=0, 6-8=1, 9-11=2, 12-14=3, > 15=4
• Compliance (mL/cm H₂O)
  – > 80=0, 60-79=1, 40-59=2, 20-39=3, and < 19=4

Results

• Mortality:
  – 33 (36%) in ECMO vs 45 (50%) non-ECMO
  – One extra survivor for every 6 patients tx w/ECMO
  – N=180 randomized to 90 in each group
• Main diagnosis: Pneumonia
• 85 hypoxic / 5 hypercarbic
• VV: from Neck / in Groin
• Rest Settings and 30% FiO₂
• Decannulation if PIP < 30 and FiO₂ < 60%
Who ends up on ECMO?

**ECMO Triggers**

- "Refractory hypoxia/hypoxemia"
  - Neonatal oxygenation criteria:
    - Oxygenation Index (OI): \(\frac{\text{MAP} \times \text{FiO}_2}{\text{PaO}_2}\)
    - \(\text{OI} \geq 20\): consider ECMO
    - \(\text{OI} \geq 40\): ECMO

- Mechanical ventilation prior to ECMO; pediatric < 10 days vs. adult < 7 days

- Concomitant illnesses
  - Malignancy (arguable)
  - CNS hemorrhage
  - Severe neurologic compromise
  - Other incurable disease

**ECMO Contraindications**

- Extracorporeal Life Support Organization (ELSO)
  - Registry of patients currently 87,366
  - [www.elso.org](http://www.elso.org)

- Alain Combes, EOLIA, NCT01470703
  - Randomized controlled trial VV ECMO for ARDS
  - Final data collection July 2017?

- Petr Ostadal, NCT02301819
  - Randomized controlled trial VA ECMO for heart failure
  - Final data collection June 2019?

- Daniel Brodie, International ECMOnet

- AHA guidelines 2015

**Case:**

- VA ECMO
  - 10 Fr Arterial
  - 22 Fr Venous
  - Provided 1640 mL/min flow
  - Sweep 700mL/min
  - Mixed venous sat of 72-80%
  - CRRT for fluid removal
  - In 4 days return of cardiac function and able to be decannulated
  - Discharged home 2 months recovery

**Future Research**

- Alain Combes, EOLIA, NCT01470703
  - Randomized controlled trial VV ECMO for ARDS
  - Final data collection July 2017?

- Petr Ostadal, NCT02301819
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Mission
To provide collaborative high quality extracorporeal life support services for critically ill patients through a multidisciplinary approach in Hawaii and the Pacific region.

Our Mission:
To provide collaborative high quality extracorporeal life support services for critically ill patients through a multidisciplinary approach in Hawaii and the Pacific region.
- Collaboration
- Multidisciplinary
- High Quality

Mission

10 Years: 2007-2016
- Total referrals: 165
- Total runs: 65
  - NICU: 32
  - PICU: 22
  - Adult: 11
- 7 mainland ECMO transports
Hanuola ECMO Program: 2007-2017

ECMO Case Volume

ECMO: Is a 4-letter word

HOPE

Thank You!
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