UI Heart and Vascular Center

Principles of ECMO Physiology and Methodology:
Respiratory Therapy’s Role in ECLS Patient Management

Ryan Frede RRT-NPS
Objectives

• Identify key concepts of ECMO methodology and physiology.

• Describe mechanical equipment used to perform ECMO.

• Demonstrate an understanding of patient populations appropriate for ECMO support.

• Review gas exchange physiology.

• Identify and apply underlying principles necessary for proper patient respiratory management.

• Recall medical and mechanical emergency strategies.
Extracorporeal

A procedure in which blood is taken from a patient’s circulation to have a process applied to it before it is returned to the circulation. All of the apparatus carrying the blood outside the body is termed the extracorporeal circuit.

- Hemodialysis
- Hemofiltration
- Plasmapheresis
- Apheresis
- Extracorporeal membrane oxygenation (ECMO)
- Cardiopulmonary bypass during open heart surgery.

Other procedures

Extracorporeal shock wave lithotripsy (ESWL), which is unrelated to other extracorporeal therapies, in that the device used to break up the kidney stones is held completely outside the body, whilst the lithotripsy itself occurs inside the body.

Extracorporeal radiotherapy, where a large bone with a tumour is removed and given a dose far exceeding what would otherwise be safe to give to a patient [citation needed].

External links

- Extracorporeal Circulation @ MedicalGlossary.org
## FY2018 ELSO/ECMO Data

<table>
<thead>
<tr>
<th>Department</th>
<th># Patient</th>
<th>Survived ECLS</th>
<th>Percent</th>
<th>Survive to DC or Tx</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NICU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp</td>
<td>3</td>
<td>3</td>
<td>100%</td>
<td>1</td>
<td>33%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ECPR</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>PICU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp</td>
<td>5</td>
<td>4</td>
<td>80%</td>
<td>4</td>
<td>80%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>2</td>
<td>1</td>
<td>50%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>ECPR</td>
<td>5</td>
<td>4</td>
<td>80%</td>
<td>2</td>
<td>40%</td>
</tr>
<tr>
<td><strong>Adult</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp</td>
<td>21</td>
<td>16</td>
<td>76%</td>
<td>14</td>
<td>66%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>19</td>
<td>15</td>
<td>79%</td>
<td>8</td>
<td>42%</td>
</tr>
<tr>
<td>ECPR</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
## 2018 ELSO/ECMO July Data Comparison
(Accumulative Data)

<table>
<thead>
<tr>
<th></th>
<th># of Patients</th>
<th>Survived ECLS</th>
<th>Percent</th>
<th>Survive to DC or Tx</th>
<th>Percent</th>
<th>Patients</th>
<th>Survived ECLS</th>
<th>Percent</th>
<th>Survive to DC or Tx</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neonatal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp</td>
<td>53</td>
<td>40</td>
<td>75%</td>
<td>22</td>
<td>41%</td>
<td>30,934</td>
<td>25,990</td>
<td>84%</td>
<td>22,599</td>
<td>73%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>35</td>
<td>15</td>
<td>42%</td>
<td>4</td>
<td>11%</td>
<td>7,794</td>
<td>5,063</td>
<td>64%</td>
<td>3,231</td>
<td>42%</td>
</tr>
<tr>
<td>ECPR</td>
<td>7</td>
<td>4</td>
<td>57%</td>
<td>3</td>
<td>42%</td>
<td>1,718</td>
<td>1,140</td>
<td>66%</td>
<td>694</td>
<td>41%</td>
</tr>
<tr>
<td><strong>Pediatric</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp</td>
<td>27</td>
<td>15</td>
<td>55%</td>
<td>11</td>
<td>40%</td>
<td>8,820</td>
<td>5,953</td>
<td>67%</td>
<td>5,079</td>
<td>58%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>36</td>
<td>23</td>
<td>63%</td>
<td>15</td>
<td>41%</td>
<td>10,462</td>
<td>7,177</td>
<td>68%</td>
<td>5,375</td>
<td>52%</td>
</tr>
<tr>
<td>ECPR</td>
<td>14</td>
<td>9</td>
<td>64%</td>
<td>5</td>
<td>35%</td>
<td>3,946</td>
<td>2,262</td>
<td>57%</td>
<td>1,643</td>
<td>42%</td>
</tr>
<tr>
<td><strong>Adult</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resp</td>
<td>107</td>
<td>72</td>
<td>67%</td>
<td>67</td>
<td>62%</td>
<td>16,337</td>
<td>10,857</td>
<td>66%</td>
<td>9,264</td>
<td>59%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>79</td>
<td>48</td>
<td>60%</td>
<td>29</td>
<td>36%</td>
<td>15,942</td>
<td>8,865</td>
<td>55%</td>
<td>6,379</td>
<td>42%</td>
</tr>
<tr>
<td>ECPR</td>
<td>5</td>
<td>3</td>
<td>60%</td>
<td>2</td>
<td>40%</td>
<td>4,952</td>
<td>1,896</td>
<td>38%</td>
<td>1,381</td>
<td>29%</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>363</td>
<td>229</td>
<td>63%</td>
<td>158</td>
<td>43%</td>
<td>100,905</td>
<td>69,203</td>
<td>68%</td>
<td>55,645</td>
<td>56%</td>
</tr>
</tbody>
</table>
First ECMO Survivor

What does ECMO do?

• The physiologic goal of ECMO is to improve tissue oxygen delivery, remove CO2, and allow normal aerobic metabolism to continue while lung/heart “rest” takes place.

• Provide cardio-pulmonary support during an acute, reversible, injury phase
Types of ECMO

• **Venoarterial (V-A)**
  - Blood is drained from a **vein** to the ECMO circuit and is returned to an **artery**.
  - Used for cardiac and respiratory failure patients

• **Venovenous (V-V)**
  - Blood is drained from a **vein** to the ECMO circuit and is returned to a **vein**.
  - Used only for respiratory failure patients
## Comparing the Two

<table>
<thead>
<tr>
<th></th>
<th>VA</th>
<th>VV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adds afterload</td>
<td>In and out right side</td>
</tr>
<tr>
<td></td>
<td>Decreased PL</td>
<td>Double lumen cannulas</td>
</tr>
<tr>
<td></td>
<td>Risk of arterial inflow,</td>
<td>Normal LV pulsation</td>
</tr>
<tr>
<td></td>
<td>emboli</td>
<td>High R side pO$_2$ for</td>
</tr>
<tr>
<td></td>
<td>Carotid ligation</td>
<td>PHTN</td>
</tr>
<tr>
<td></td>
<td>Central cannulation</td>
<td>No effect PL/AL</td>
</tr>
<tr>
<td></td>
<td>Deoxygenated blood to the</td>
<td>Microemboli/air to</td>
</tr>
<tr>
<td></td>
<td>lungs</td>
<td>lungs</td>
</tr>
<tr>
<td></td>
<td>Only way to provide</td>
<td>Oxygenated blood to the</td>
</tr>
<tr>
<td></td>
<td>cardiac support</td>
<td>lungs</td>
</tr>
<tr>
<td></td>
<td>SpO$_2$ near 100%</td>
<td>Respiratory support</td>
</tr>
<tr>
<td></td>
<td>Ideal SVO$_2$ 65-75%</td>
<td>SpO$_2$ in the 70%’s</td>
</tr>
</tbody>
</table>
VV ECMO: Pros and Cons

• VV ECMO is probably safer than VA ECMO.

• Single vessel cannulation

• Air and thrombo-emboli will go to the lungs to be absorbed

• Blood entering the cerebral arterial tree is less highly oxygenated and under less pressure. This difference may decrease the risk of neurological injury occurring with VA ECMO.

• The potential for ischemic injury to the lungs is decreased with VV ECMO.

• A disadvantage of VV ECMO is that it is not able to provide direct circulatory support.
VV ECMO
Recirculation

- The understanding of the concepts of recirculation is critical to successful application of VV ECMO

- Four factors that affect recirculation and oxygen delivery
  - Pump flow
  - Catheter position
  - Cardiac output
  - Right Atrial Size/Intravascular Volume
VA ECMO: Pros and Cons

- Non-pulsatile support
- Decrease arterial waveform with increased flow
  - Follow MAPS
- Watch for LV distention
  - Goal is to decompress the heart to allow healing
- Minimize afterload: Milrinone, Nipride, LV vent
- Indications of adequate support:
  - Urine output, SVO2, acid-base, lactate, serum creatine, LFTs
VA ECMO
VA ECMO
VA ECMO

Central veno-arterial ECMO cannulation approach
an oxygen molecule: $\text{O}_2$
• Oxygen Content
• Oxygen Delivery
• Oxygen Consumption
Ventilation

CO2 Clearance

OXYGEN DELIVERY/CONSUMPTION

A/V O₂ DIFFERENCE

ARTERIAL O₂ CONTENT

VENOUS O₂ CONTENT

VENOUS RETURN

BMR + SEPSIS + WORK

CO2 Production

O₂ CONSUMPTION (cc/min)
**O₂ KINETICS**

**VENOUS O₂ CONTENT**
16 cc/dL
sat 80%

**ARTERIAL O₂ CONTENT**
20 cc/dL, sat 100%

**CARDIAC OUTPUT**
3.2 L/min

**O₂ DELIVERY**
\( \dot{D}O_2 \)
600 cc/min

**O₂ CONSUMPTION**
\( \dot{V}O_2 \)
120 cc/min

**REE**
Fuel + O₂

**\( \dot{D}O_2 / \dot{V}O_2 \)**
\[
\frac{600}{120} = \frac{5}{1}
\]

**O₂ EXTRACTION RATIO**
REE = 5 cal/LO₂
O_2\text{ Content} = \text{Hb} \times \%\text{ sat} \times 1.36 \ (\text{plus dissolved O}_2)
INTERPRETING THE DO\textsubscript{2}/VO\textsubscript{2} DIAGRAM

- Metabolism
  - Hyper
  - Normal
  - Hypo

- Oxygen Delivery

- Shock
- Normal
- Excess Perfusion and AV Fistula

O\textsubscript{2} Delivery Reserves
**DO₂/VO₂ Ratio**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Ratio</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>5:1</td>
<td>80%</td>
</tr>
<tr>
<td>Critical low point</td>
<td>2:1</td>
<td>50%</td>
</tr>
<tr>
<td>Ischemia, shock, Supply dependency</td>
<td>&lt; 2:1</td>
<td></td>
</tr>
</tbody>
</table>

*Ischemia time/dose can be quantitated*
Gas Exchange on ECLS

- **Oxygen Delivery**
  - Native Lungs
    - Hemoglobin, Saturation, Cardiac Output
  - Membrane Lung
    - Rated Flow
    - Circuit Design based on Total Support

- **CO₂ Removal**
  - Native Lungs
    - Volume, Respiratory Rate
  - Membrane Lung
    - Membrane Surface Area
    - Sweep Gas
    - Unrelated to Blood Flow
Rules to LIVE by:

• **PaCO₂** is related to the rate of sweep gas flow
  • Increasing sweep gas will decrease PCO₂
  • Decreasing sweep gas will increase PCO₂

• **PaO₂** is related to your pump flow
  • Increasing pump flow should increase PO₂
  • VV ECMO: Oxygen Content
  • VA ECMO: Oxygen Delivery
Indications for ECMO

• Offered to patients who have reversible respiratory and/or cardiac failure that is unmanageable using maximum medical and pharmacological strategies.

• Bridge to recovery, transplant, device, or decision.
Indications for ECMO

1. In hypoxic respiratory failure due to any cause (primary or secondary) ECMO should be considered when the risk of mortality is 50% or greater, and is indicated when the risk of 80% or greater.

   - PaO2/FiO2 < 80; OI >30; Murray Score >3; FiO2 >0.9; PEEP ≥ 15

   - If you’re considering proning/paralyzing a patient, you should be considering ECMO.
Indications for ECMO

• 2. CO2 retention due to asthma or permissive hypercapnia with a PaCO2 > 80 or inability to achieve safe inflation pressures (Pplat ≤ 30 cm H₂O) is an indication for ECMO.

• 3. Severe air leak syndrome
Indications for ECMO

• Serious systemic hypotension
• Acute hypoxemia (cardiac related)
• Cardiogenic shock with
  • Hypotension requiring inotropes
  • Low cardiac output despite adequate intravascular volume
  • Intraaortic balloon counterpulsation, if appropriate.
  • Myocardial stun
• Bridge to transplant via other assistive device.
Pediatric Indications

- Cardiac surgical population
  - Pre-op stabilization
  - Failure to wean from bypass
  - Low cardiac output syndrome

- Non-surgical
  - ECPR
  - Myocarditis, cardiomyopathy, arrhythmias, pulmonary HTN
  - Respiratory illnesses
  - Pulmonary hemorrhage
Neonatal Indications

- PPHN
- Meconium Aspiration
- Severe air leak syndrome
- CDH
Contraindications

- Incurable malignancy
- Advanced MSOF
- Extreme prematurity
- Severe CNS injury
- *Special consideration for non-transplantable cases
Pulmonary management on ECMO
Repeat after me.....

LUNG

REST
• Minimize FiO₂, PIP (distending pressure), and plateau pressure.
• Attempt to decrease WOB (P 0.1)
• Utilize any mode (PC, VC, PS, PRVC, BiVent, HFOV)
• Diuresis/CRRT
• Pulmonary toilet (suctioning, bronchoscopy)
• Extubation
• Early tracheostomy
• DO NOT attempt lung recruitment during the first 48 hours
Determining Adequacy of Support

- Blood gas and SpO2
- SVO2
- Lactate
- VA: BP (MAP)
- Assess your patient
Pre-, Post-, and Patient gas….WHAT?

• We compare all three gases.
  • Pre-ox gas CO2 to patient CO2
    • Trending CDI
  • Pre-ox gas to post-ox gas
    • CO2 and PaO2
    • Still have clearance?
    • 10 torr difference for CO2
    • Post-ox PaO2 >90
Your patient is a 70kg Influenza on VV ECMO on rest vent setting + the following ECMO settings:

- Pump flow of 4.2L
- Sweep gas 8L
- Pump FiO₂ 100%
- Acceptable ranges of blood gases are Patient PO₂ 40-80, PCO₂ 30–50, and Post Membrane PO₂ 90 – 400

<table>
<thead>
<tr>
<th></th>
<th>Patient</th>
<th>Pre</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.32</td>
<td>7.31</td>
<td>7.40</td>
</tr>
<tr>
<td>PCO₂</td>
<td>59</td>
<td>58</td>
<td>41</td>
</tr>
<tr>
<td>PO₂</td>
<td>45</td>
<td>40</td>
<td>537</td>
</tr>
<tr>
<td>BE</td>
<td>+5</td>
<td>+5</td>
<td>+5</td>
</tr>
<tr>
<td>Sat</td>
<td>84%</td>
<td>78%</td>
<td>100%</td>
</tr>
</tbody>
</table>
VA Physiology

- Factors to consider:
  - Native cardiac output
  - Cannula position
femoral cannulation

central cannulation
When can we come off ECMO? (VV Support)

- Have the lungs improved?
  - Chest x-ray?
- Can the patient tolerate stimulation/activity?
  - Svo2?
  - Saturations?
- Pump flow and sweep
  - As patients lungs start to do more work the patient will require less pump flow and sweep.
- Trial offs are easy…shut off sweep/clamp gas line.
  - May need to increase ventilator settings a little during trial.
When can we come off ECMO? (VA support)

- Has the cardiac function returned/improved?
- Wean pump flow to minimum that circuit requires
  - ¼” circuit typically 200cc/min
  - 3/8” circuit typically 500cc/min
- Hoffman clamp applied to bridge
  - Once minimal flow established to circuit
    begin slowly opening the Hoffman clamp
- Hoffman clamp vs. clamp off trial
- Per policy we don’t wean sweep or FIO2
  - Single ventricles Hoffman wean to clamp off
Coagulation Management
Procoagulant vs. Anticoagulant

- Continuous contact between circulating blood and the foreign surface of the circuit initiates coagulation. (Procoagulant Activity)

- In an attempt to minimize this activity and prevent thrombosis in the ECLS circuit and exogenous anticoagulant (heparin) is necessary. (Anticoagulant Activity)

Stress Reduction Kit

Bang
Head
Here

Directions:
1. Place kit on FIRM surface.
2. Follow directions in circle of kit.
3. Repeat step 2 as necessary, or until unconscious.
4. If unconscious, cease stress reduction activity.
Testing

- Activated Clotting Time (ACT)
- Antithrombin III (ATIII)
- Heparin Assay (Anti-Xa)
- Prothrombin Time (PT)
- Partial Thromboplastin Time (PTT)
- Fibrinogen
- Thromboelastograph (TEG)
Clotting Cascade
Heparin

• Action:
  • Accelerating the action of antithrombin
  • Inhibit thrombin and factor Xa
  • Average Heparin infusion rate 10-30 u/kg/hr
  • Heparin is dependent on circulating antithrombin for most of its anticoagulant activity.
Bleeding

- Most common complication
- Anticoagulation, platelet dysfunction
- Prevention
  - No subcutaneous therapies
  - Try not to remove or add lines once on ECMO
  - Suctioning, ng tubes, foleys...
- Communication is key!
This patient is being continuously anticoagulated with **Heparin** for the purpose of ECMO

- NO subcutaneous injections
- NO finger/heel sticks for point of care testing
- **DO NOT REMOVE** intravascular devices or any modes of therapy that may cause bleeding
- Swabs **ONLY** for oral care. Use toothettes and gentle suctioning. Assess for risk of bleeding with oral pharyngeal suctioning. (N-11.046)
- **HOLD** PO anticoagulants
- If you have any questions, please speak with your bedside **ECMO Specialist**
Emergency Management

sucking air, squirting blood, pump failure, accidental decannulation
Protect the Cannulas and the ECMO Circuit

- Discourage approach to the cannula side of the patient
- If someone must approach from the cannula side of the patient…STAND GUARD!!!
- Watch cannulas closely when doing physical cares of all kinds
- Get help…you should guard the cannulas and delegate the cares to others if the ES is unable to guard them
- Obtain approval from the ES before moving the patient
- Always have plenty of help and a doctor’s “OK”/order for patient activity/cares
How do we stay prepared to care for these complex patients.....

• Ask yourself these questions every time you take care of an ECMO patient.

  1. How do I protect the patient in the event of an emergency?
  2. Will this patient code during an ECMO emergency?
  3. How can I assist the ECMO specialist until more help arrives?
How do I Protect the Patient?

- In the event of a circuit disruption (**blood escaping from the system, air entrained in the circuit, a mechanical failure or an accidental decannulation**) how do I protect the patient?

**AVB** to remove a patient from ECMO

- **Arterial line**
- **Venous line**
- **Bridge**
Will this Patient Code?

• Pressors should be readily available

• Have volume readily available: Albumin, NS, blood.

• Compressions or no compressions??

• Shock or no shock??

• Emergency Vent Settings
• Emergency Vent Settings

  • Discussed with Staff/Fellow physicians when patient is initiated onto ECMO

  • Should attempt to be adequate to support patient in the event of ECMO emergency

  • Should be put into orders as a note under the current vent orders

  • Should be written and taped onto ventilator
Conclusion

• ECMO is an effective support therapy for patients in severe respiratory or cardiac failure.

• VA and VV ECMO have distinct risks and benefits.

• The physiology of gas exchange is the key to ECMO.
  • Oxygen content
  • Oxygen delivery
  • Oxygen consumption
Conclusion

• Pump flow affects oxygenation. Sweep flow affects CO2 clearance.

• Indications/contraindications of ECMO – It’s a bridge, not a treatment.

• RT’s play a key role in initiation, daily and emergency management, and discontinuation of ECMO support.

• Don’t be afraid to be a patient advocate…ask questions, be involved, communicate.
Thank you!

ryan-frede@uiowa.edu