ECMO: a 2017 primer

Avery Tung, M.D.
Department of Anesthesia and Critical Care
University of Chicago

Disclosures

I am the critical care section editor for Anesthesia & Analgesia

- We have published ECMO papers

It is entirely possible I will discuss an off-label entity

- The FDA classifies ECMO as a class II device (special controls* may reasonably improve safety)

*Geometry and design consistent with intended use
*Devices and accessories
*Sterility and shelf life
*Clinical effectiveness for indication
*Adequate labelling of equipment


Outline

• The ECMO landscape today
  – It wouldn't even exist if EBM were in charge
• A brief description
  – Techniques, terminology and equipment
• Applications
  – What kind of patient ends up on ECMO & how do they do?
• Case examples
  – It can sound crazy until you get used to it
24 yr M with ARDS after MVA
Discharged on HD #56
NEJM 1972;286:629-34

Extracorporeal Membrane Oxygenation in Severe Acute Respiratory Failure
A Randomized Prospective Study
Walter N. Zapol, MD; Michael T. Soder, MD; Robert F. Fallat, MD; Robert H. Bartlett, MD; L. Harvey Taylor, MD; E. Coventry Pimlic, MD; Arthur W. Thomas, MD; Reginald C. S. Zuckerman, MD; Philip C. Post, MD; and Carol G. Miller, Jr., MD
JAMA 1979;242:2193-6

90 hypoxemic patients* randomized
ECMO vs. conv. ventilation

ECMO: No benefit by PRCT!
40 patients with hypoxic respiratory failure

Stopped early for excess mortality in ECMO group (70 vs 60%)

Morris (1994)

Zapol (1979)

1st ECMO

H1N1

Two negative RCTs but still alive!

Pubmed citations for ARDS and ECMO, 1970-current in 5 year increments


180 patients randomized to ECMO* or conventional ventilation

90 control patients
  • 53% died

90 ECMO patients**
  • 37% died

*Via referral to ECMO center
**24 did not get ECMO and 5/24 (21%) died

Lancet 2009;374:1351-63
ECMO: Terminology

- **Inflow**: carries blood from the patient to the ECMO device
- **Outflow**: Conduit carrying blood from the ECMO device to the patient
- **V-A**: From the vein into the artery
- **V-V**: From the vein into both the artery and vein
- **VV-A**: From two veins into the artery
- **Oxygenator**: Adds oxygen to blood, controls temperature, and removes CO₂
- **RPM**: how fast the pump is spinning
- **Flow**: Estimated output generated by the device
- **Chatter**: shaking of the inflow cannula due to intermittent suction events that occlude the tip of the inflow cannula
ECMO pump FAQ

How is the flow generated?
- Mostly centrifugal pumps. 2nd generation pumps are as reliable and smaller than roller designs, and have intrinsically limited outflow pressures. CF pumps also do not pump visible air.

Do they cause more hemolysis?
- Probably not. Early centrifugal pumps generated considerable heat & shear stress, but modern designs have addressed those issues somewhat.

What are problems with centrifugal pumps?
- CF pumps are both afterload and preload sensitive, so maintaining a stable low level of flow (<500cc/min) is difficult. Roller pumps can explode the circuit if afterload is too high.

How is flow monitored?
- Internally & via Doppler flowmeters clipped onto the ECMO tubing.
And anticoagulation

- Heparin is most common
  - PTT 45-70 depending on extent of bleeding & other factors
- Argatroban can be used for HIT (+) patients
  - Monitoring is normally done via PTT
- Several case reports of Bilvalrudin exist
  - These reports followed PTT/ACT & had no difficulty
  - Blood stagnation can lead to clot due to rapid cleavage
  - Bilvalrudin is renally cleared
- Be careful following Anti Xa levels!
  - A therapeutic Anti Xa level can coexist with an extremely high PTT and lead to undesired bleeding
So what kind of patient needs ECMO?

ECMO is for cardiorespiratory failure

Either:

• The heart isn’t pumping enough blood to maintain adequate blood flow & pressure

Or

• The lungs are failing to adequately maintain gas exchange with the blood (PO₂ or PCO₂)

Or both…

ECMO for ARDS

ARDS after MI
VV ECMO support
R Fem to LIJ
In ARDS

ECMO is used primarily to restore oxygenation
- Frequently cardiac function is adequate

Inflow and outflow are both VENOUS
- Goal is to raise venous O₂ content

ECMO does not provide cardiovascular support
- ARDS & cardiovascular instability is often an indication for VA ECMO

Efficacy is often limited by recirculation
- If the cannulae are too close together

Variants on VV ECMO

Inflow: Femoral Vein
Outflow: RIJ or Subclavian vein

Inflow: RIJ
Outflow: RIJ or Subclavian vein

Inflow: Femoral vein
Outflow: Femoral vein

Cycling: the Achilles heel of VV ECMO

- 62 yr M
- ARDS after MI
- VV ECMO
- RIJ to RIJ
- 4.8LPM (3400rpm)
- 6lpm sweep
- FiO₂ 100%
- 7.42/46/78
• 71 yr M
• ARDS after Thoracotomy
• VV ECMO
• Ref to LIJ
• 5.9LPM (4600rpm)
• 4lpm sweep
• FiO2 100%
• 7.43/37/69

Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial

180 patients randomized to conventional care vs. transfer to an ECMO center
• 60% pneumonia, 7-8% trauma
• Murray score >3.0 & potentially reversible

<table>
<thead>
<tr>
<th>PaO2/FiO2 on 100% (mmHg)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 300</td>
<td>225-299</td>
<td>175-224</td>
<td>100-174</td>
<td>&lt;100</td>
<td></td>
</tr>
</tbody>
</table>

CXR quadrants

<table>
<thead>
<tr>
<th>CXR quadrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>≤ 5 6-8 9-11 12-14 ≥ 15</td>
</tr>
</tbody>
</table>

PEEP (cm H2O)

<table>
<thead>
<tr>
<th>PEEP (cm H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 5 6-8 9-11 12-14 ≥ 15</td>
</tr>
</tbody>
</table>

Compliance (ml/cm H2O)

<table>
<thead>
<tr>
<th>Compliance (ml/cm H2O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 80 79-60 59-40 39-20 ≤ 19</td>
</tr>
</tbody>
</table>

Conventional mgmt
• Murray = 3.5
  – P/F = 76, PEEP=10, compliance = 27
• Low TV: 70%
• CVVH: 84%
• Steroids: 58%
• Prone: 42%
• HFOV: 14%
• NO: 7%

At 6 months: ECMO 63%, Conventional 47%
Extracorporeal Membrane Oxygenation for 2009 Influenza A(H1N1)
Acute Respiratory Distress Syndrome

68 patients with influenza-associated ARDS who underwent ECMO

Results:
- Murray score 3.8
- VV in 63/69 patients, VA in 6 patients
- 7-15 days of ECMO support
- Survival to ICU discharge: 48%
- Survival to hospital discharge: 47%
- Causes of death:
  - Intracranial hemorrhage: 43%
  - Respiratory failure: 29%
  - Hemorrhage: 20%

Unanswered questions

- When to initiate ECMO
  - ELSO recommends P/F<80, PCO2>80, or PIP>30 but is earlier ECMO better?
- What patients should receive ECMO
  - Severe ARDS with preserved end organ function & can tolerate anticoagulation
- How to manage mechanical ventilation while on ECMO
  - Lungs should be "rested" but how much rest is optimal?
- How does ECMO improve (?) survival in ARDS
  - Better oxygenation? Lung rest?
- VV or VA ECMO
  - Often, VV ECMO decreases the need for pressors

Medical Ethics

"Finally, and most importantly, it would be cruel to ignore the request of the patient to remain on ECMO and tell her that the device would be removed against her wishes. We and others believe that cruelty is unethical and the patient would clearly suffer emotionally at the thought of impending death against her wishes."

"ECMO 2009;302:1888-95"
17 patients on inotropic or vasoconstrictive therapy who underwent VV ECMO for ARDS

None required conversion to AV ECMO

<table>
<thead>
<tr>
<th>Patient</th>
<th>NE at Time</th>
<th>NE After</th>
<th>NE After</th>
<th>NE After</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>2</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>11.5</td>
<td>6.25</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>1</td>
<td>1.25</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>43</td>
<td>40</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>17</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>5</td>
<td>9</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>49</td>
<td>45</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>95</td>
<td>28</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>29</td>
<td>21</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>15</td>
<td>29</td>
<td>18</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>17</td>
<td>58</td>
<td>68</td>
<td>52</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Group median (IQR): 20 (11.5–30); 9 (2–21); 4.5 (3–14); 7 (5–8)

2. The blood must go round and round*

- BP = CO (flow) * SVR
- Both adequate BP and CO are necessary for life
  - MAP > 60 mmHg
  - CO > 4 lpm or CI > 2.2
- Inadequate BP or CO (or both) = shock:
  - ↓ UO or Mental status
  - ↑ Lactate (2 mmol/L)
  - ↓ SvO2 (<60%)
- ECMO increases CO
  - Using a pump
  - Hopefully ↑ CO leads to ↑BP

ECMO for cardiogenic shock

- 43 yr F with giant cell myocarditis
- 52 yr M with nonischemic cardiomyopathy

*1. The air must go in and out

N.B. Rules reversed during CPR
In cardiogenic shock:

- ECMO supports blood pressure and cardiac output
  - By pumping blood from vein to artery
- ECMO generates negative pressure in the venous cannula and flow is nonpulsatile
  - So flow is still limited by venous return
- An oxygenator is almost always needed
  - Because native flow through the lungs is usually poor
- Three big issues
  - Distal limb ischemia
  - Thrombosis (no blood flow through the lungs)
  - “North South” syndrome

Limb ischemia

- The most common complication of VA ECMO (20-50% incidence)
- Worse in smaller patients
- Distal perfusion cannulae reduce the incidence dramatically
Thrombosis

Incidence: Unknown
- But probably increasing with increasing ECMO use

Risk factors: Ventricular distension
- Aortic insufficiency
- High afterload
- Volume overload
- Poor venous drainage

Solutions:
- RA vent
- Transapical vent
- Transaortic vent
- PA vent

“North South syndrome”

- In cases where native gas exchange is poor but cardiac function is unimpaired, VA ECMO results in two sources of cardiac output
  - Heart & ECMO
- The heart pumps deoxygenated blood into the ascending aorta
  - (“North”)
- ECMO pumps oxygenated blood into the femoral artery
  - (“South”)
- The two streams meet somewhere in the aorta
  - The location depends on the balance between the cardiac outputs
- The result can be (relatively) deoxygenated blood perfusing the head
What conditions commonly lead to VA ECMO?

Myocardial Infarction
- With systolic dysfunction
- With mitral regurgitation
- With VSD
- With intractable arrhythmia

Post cardiac surgery
- Inadequate preservation while cross-clamped

Pulmonary HTN/Pulmonary embolus
- With right heart systolic failure

Zebra causes of R or L systolic dysfunction
- Myocarditis
- Idiopathic
- Graft dysfunction after transplant
- s/p LVAD
- Drug overdose

Outcomes?
Since the year 2000, patient treatment and practice with ECMO have considerably changed as the result of research findings and technological advancements.

Over the past four decades, only four RCTs have been published that compared the intervention versus conventional treatment at the time of the study.

Clinical heterogeneity across these published studies prevented pooling of data for a meta-analysis*

*One RCT involved pumpless ECMO

Survival to hospital discharge:
For Respiratory failure (VV)
- 84% in neonates
- 76% in children
- 50% in adults
For Cardiac failure (VA)
- 45% in children
- 38% in adults
Contemporary Outcomes of Venoarterial Extracorporeal Membrane Oxygenation for Refractory Cardiogenic Shock at a Large Tertiary Care Center

Kaplan Meier 3-month Survival Estimates

- PCS
- AMI
- Graft Failure
- ADHF
- Other

ASAIO Journal 2015;61:463-469

Extra-cor pulmosal membrane oxygenation for refractory cardiogenic shock after adult cardiac surgery: a systematic review and meta-analysis


24 studies and 1,926 patients, 1992-2016

30.8% survival rate to hospital discharge

- Adverse prognostic indicators:
  - Age > 70
  - High Euroscore
  - ARF while on ECMO
  - Rising lactate while on ECMO
  - ECMO > 48h

J Cardiothorac Surg 2017;12:55

ECLS Registry Report

Overall Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Survived ECLS</th>
<th>Survived to D/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate Pulm</td>
<td>83%</td>
<td>72%</td>
</tr>
<tr>
<td>Neonate Cardiac</td>
<td>65%</td>
<td>41%</td>
</tr>
<tr>
<td>Peds Pulm</td>
<td>67%</td>
<td>58%</td>
</tr>
<tr>
<td>Peds Cardiac</td>
<td>69%</td>
<td>51%</td>
</tr>
<tr>
<td>Adult Pulm</td>
<td>66%</td>
<td>58%</td>
</tr>
<tr>
<td>Adult Cardiac</td>
<td>57%</td>
<td>41%</td>
</tr>
</tbody>
</table>
Complications of Extracorporeal Membrane Oxygenation for Treatment of Cardiogenic Shock and Cardiac Arrest: A Meta-Analysis of 1,866 Adult Patients

Richard Cheng, MD, Sarv Prihodko, MD, Michele Kittleson, MD, PhD,
Iraj Farhang, MD, PhD, Faraz Ekekhoe, MD, Steven L. Connors, MD,
Farzad Farhang, MD, and Reto K. Abate, MD

35% survival

Ann Thorac Surg 2014;97:610-6

Extracorporeal Life Support Organization Registry International Report 2016

Table 10. Adverse Events During ECLS by Age and Indication

<table>
<thead>
<tr>
<th>Event</th>
<th>Neonate (%)</th>
<th>Pediatric (%)</th>
<th>Adult (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemorrhage</td>
<td>1.6</td>
<td>3.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Mechanical pump malfunction</td>
<td>1.6</td>
<td>2.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Cardiac ischemic dysfunction</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Carotid reperfusion</td>
<td>7.9</td>
<td>18.5</td>
<td>19.2</td>
</tr>
<tr>
<td>Surgical complications</td>
<td>6.3</td>
<td>12.6</td>
<td>10.8</td>
</tr>
<tr>
<td>CNS hemorrhage</td>
<td>7.6</td>
<td>8.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Renal failure</td>
<td>6.8</td>
<td>16.8</td>
<td>17.5</td>
</tr>
<tr>
<td>Cardiac</td>
<td>1.5</td>
<td>1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Mechanical pump malfunction</td>
<td>2.1</td>
<td>7.0</td>
<td>6.4</td>
</tr>
<tr>
<td>Cardiac ischemic dysfunction</td>
<td>7.2</td>
<td>15.0</td>
<td>16.3</td>
</tr>
<tr>
<td>Carotid site hemorrhage</td>
<td>21.8</td>
<td>26.2</td>
<td>20.2</td>
</tr>
<tr>
<td>Surgical complications</td>
<td>11.2</td>
<td>16.8</td>
<td>10.2</td>
</tr>
<tr>
<td>CNS hemorrhage</td>
<td>8.4</td>
<td>5.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Renal failure</td>
<td>10.5</td>
<td>7.2</td>
<td>12.3</td>
</tr>
<tr>
<td>Intensive care</td>
<td>7.1</td>
<td>11.0</td>
<td>13.8</td>
</tr>
</tbody>
</table>
Three issues

• ECMO in CPR
  • Why do chest compressions when you have a centrifugal pump?
• Solutions for inadequate oxygenation
  • A cannula in every spot!
• A case example
  • ECMO made very complicated

ECPR?

The incidence of "load & go" out-of-hospital cardiac arrest candidates for emergency department utilization of emergency extracorporeal life support: A one-year review

Michael Poppe, Christoph Weiser, Michael Huber, Patrick Sitzgruber, Philip Butler, Markus Neferick, Sebastian Zeier, Elisabeth Iltisereger, Raphael van Tubber, Andreas Ziegler, Hans-Ulrich, Marthof Metzner, Georg Schusterbacher,

Heribor Macier, Andreas Ziegler, Fritz Steff, Andreas Schuler

Department of Emergency Medicine, Medical University of Innsbruck, Innsbruck, Austria
Received for publication 20 December 2015; accepted 15 January 2016

364 patients

55 met "load & go" criteria (6%)
  • <75 yrs
  • Witnessed OHCA
  • VF/VF
  • No ROSC within 15 min

12 received E-ECLS

1 recovered

Resuscitation 2015;91:131-6
Rescue strategies for ECMO failure

Cycling during VV ECMO

“North South syndrome” during VA ECMO

Modified from Circulation 2014;130:1095-1104
It makes sense

- ECMO may still result in inadequate oxygenation
  - Due to inadequate native lung function
- HFOV may improve lung function
  - By reopening atelectatic alveoli
- HFOV may worsen hemodynamics
  - By increasing intrathoracic pressure
- HFOV may not fully normalize PCO₂
  - Due to inadequate tidal volumes
- ECMO can address both of those problems

Early treatment with arteriovenous extracorporeal lung assist and high-frequency oscillatory ventilation in a case of severe acute respiratory distress syndrome

Department of Anesthesiology, University Hospital, Heidelberg, Germany

22 yr MVA victim with GCS = 3

- ECMO for CO₂ control during head trauma (8 days)
- HFOV for O₂ control during aspiration ARDS (5 days)
- Survived and weaned from mechanical ventilation (16 days)


HFOV “OSCAR”
Jan 22, 2013
N=398
No benefit

HFOV “OSCILLATE”
Feb 28, 2013
N=548
Stopped early
No benefit

A 48 yr F with septic shock and lung injury

18 days on ECMO!
4 days on HFOV

Day 5
• s/p Robotic MVR
• Severe pulmonary hemorrhage & ARDS
• 21 days on ECMO
• 6 days on HFV

Day ~120

Use of HFPV for Adults with ARDS: The Protocolized Use of High-Frequency Percussive Ventilation for Adults with Acute Respiratory Failure Treated with Extracorporeal Membrane Oxygenation

24 ARDS survivors managed with ECMO and HFOV

“This report suggests that the time required for adults with ARDS to recover and wean from ECMO may be reduced by the protocolized use of HFPV”
Additional cannulae: VV-A ECMO

For VA ECMO
- Facilitates venous drainage
- Decompresses the heart
- Sends more output through the oxygenator
- “VV-A” ECMO

Additional cannulae: V-AV ECMO

For VA ECMO
- A venous outflow line is added
- Provides a VV component
- Raises the SvO2
- “VA-V” ECMO

For VV ECMO
- An arterial outflow is added
- Treats cardiac failure
- Adds cardiac output
- “VA-V” ECMO

The University of Michigan Experience with Veno-Venoarterial Hybrid Mode of Extracorporeal Membrane Oxygenation

23 adults
- 46% for Cardiac failure
- 38% for North-South
- 15% for Hypoxemia

Survival = 39%

ASAIO Journal 2016;62:578-83
An example

- 69 yr s/p open R lobectomy
  - Extensive dissection due to scarring from prior CABG
- Desaturated on POD#5
  - Profound R atelectasis, Bronchoscopy ineffective
- Intubated for profound hypoxemia/acidosis
  - pH 7.16, PO2 40s
- Arrested during intubation & multiple pressors started
  - 90/40 on Epinephrine, Vasopressin, Neosynephrine
- Decision to start ECMO

VA ECMO initiated

- Both oxygenation and hemodynamic support required
  - Dx: Hypoxia, Acidosis, PE, MI
- Rfem vein to Rfem artery
  - Improved oxygenation: 7.32/51/345
- But increasing pulsatility over next 24 hours
  - 69/68
  - 75/62
  - 71/58
  - 80/59
- With weaning of pressors
- And dropping PO2
  - 257
  - 221
  - 69
  - 50

Diagnosis?

- Worsening North-South syndrome
- Improving post-arrest cardiac function results in more blood passing through the patient’s lungs (and not through the ECMO oxygenator)
- The result: progressive O2 desaturation
- A good and bad sign!
  - Good: recovering heart function
  - Bad: Lungs still function poorly
- Cardiac echo supported return of LV function
Solution: VAV ECMO

- Insert another outflow cannula
  - Ideally in an upper body vein to deliver oxygenated blood to the arch
- Can adjust flows to artery & vein via clamp
  - Titrated to PO₂ and O₂ delivery
- Allows for eventual transition to VV ECMO
  - Lower complication rate
  - Higher survival rate
- In this case a LIJ cannula was placed
  - To avoid cycling & because the RIJ was occupied

It worked!

- For awhile...
  - PO₂ continued to ~50s despite 100% FiO₂ by oxygenator, 8lpm total pump flow, LIJ flow 3.8 lpm
- Clamp applied to increase LIJ flow to 4.2 lpm
  - ↑ PO₂ to 90s
  - ECMO PO₂ 200s so a fair amount of intracardiac flow
- Echo performed to evaluate cardiac function
  - Normal LV
- Plan: Remove Rfem arterial cannula & transition to VV ECMO

What happened?

- Converted to VV Rfem to LIJ
- GI bleeding
  - Heparin adjusted
- Tracheostomy
  - To facilitate weaning
- ECMO weaned
  - Sweep off % FiO₂ to room air
- Decannulated POD#16
  - In the OR
- Discharged POD#32
  - Renal & Neuro function intact!
Summary I

- Although ECMO has existed for almost 50 years, recent use has exploded
  - Newer pumps, improved oxygenators, better cannulae, less aggressive anticoagulation
- Modern ECMO offers full or partial cardiac and respiratory support
  - Through a variety of cannulation strategies
- Incrementally better success rates have allowed treatment of disease states previously considered fatal
  - PE, AFE, MI & cardiogenic shock, refractory VT, severe ARDS
- Survival rates now hover at 40% for VA and 50-60% for VV
  - Depending on the disease state

Summary II

- ECMO complications include bleeding, limb ischemia, inadequate gas exchange, renal failure, North South syndrome, stroke, and futility
  - Of these, futility is often the most challenging
- As experience with ECMO increases, patients will live longer and more challenges will arise
  - ECMO has the potential to rewrite EBM!