ECMO
ATS Fellows Track Symposium

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No Disclosures
Outline

1. ECMO circuit components
2. VV and VA ECMO patient selection
3. Common complications:
   a) Inadequate pump flow
   b) VV: hypoxemia, recirculation
   c) VA: hypotension, differential oxygenation
Circuit Components
Veno-arterial (VA)  

Veno-venous (VV)
VA ECMO

Arterial

Venous
VV ECMO
The Circuit
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECMO Blood Flow ((\dot{V}))</td>
<td>4.37 lpm</td>
</tr>
<tr>
<td>Pump Speed</td>
<td>3620 rpm</td>
</tr>
<tr>
<td>Venous Pressure ((P_{\text{ven}}))</td>
<td>-73 mmHg</td>
</tr>
<tr>
<td>Arterial Pressure ((P_{\text{art}}))</td>
<td>275 mmHg</td>
</tr>
<tr>
<td>Internal Pressure ((P_{\text{int}}))</td>
<td>300 mmHg</td>
</tr>
<tr>
<td>Temperature ((T_{\text{art}}))</td>
<td>37.3 °C</td>
</tr>
<tr>
<td>(\Delta P = P_{\text{int}} - P_{\text{art}})</td>
<td>25 mmHg</td>
</tr>
<tr>
<td>Pre-membrane saturation ((S_vO_2))</td>
<td>78.2%</td>
</tr>
</tbody>
</table>
Patient Selection
Meet Steve

35 M COVID19 ARDS day 4 IMV, prone, neuromuscular blockade, inhaled epoprostenol

VC
Vt 5cc/kg
RR 35
FiO2 100%
PEEP 18
Pplat 35

pH 7.22
PaCO₂ 60
PaO₂ 47
SpO₂ 83%

VV ECMO candidate?
Meet Sandy

55 F with palpitations for “a while”, hypotensive, rapid Afib, cool extremities
Intubated, DCCV, amiodarone, persistently hypotensive, end organ dysfunction

VC
Vt 8cc/kg
RR 30
FiO2 40%
PEEP 5
SpO2 98%

RA 18
RV 36/17
PA 35/25(28)
Wedge 24
SvO2 35%
Cl 1.3(thermo)
BP 81/62

VA ECMO candidate?
General Indications for ECMO

- Acute severe cardiopulmonary failure with high mortality risk refractory to conventional therapy
- Bridge to recovery, durable organ replacement... or decision

Use ECMO for a disease process with a solution
ECMO Discontinuation Strategies

Recovery

End Of Life Care
General Contraindications for ECMO

• Futility: too sick (irreversible multi-organ failure), on conventional therapy too long
• Preexisting life-limiting conditions: central nervous system pathology, end stage diseases (ESRD, cirrhosis, malignancy)
• Advanced age
• Limited vascular access
### Disease-specific Indications

<table>
<thead>
<tr>
<th>VA ECMO</th>
<th>VV ECMO</th>
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<tbody>
<tr>
<td>Refractory cardiogenic shock</td>
<td>Severe ARDS</td>
</tr>
<tr>
<td>Cardiac arrest (ECPR)</td>
<td>Refractory hypercarbia</td>
</tr>
<tr>
<td>Massive pulmonary embolus</td>
<td>Pulmonary injury</td>
</tr>
<tr>
<td>Environmental hypothermia</td>
<td>Bronchopleural fistula</td>
</tr>
<tr>
<td>Cardiotoxic ingestion</td>
<td>Bridge to lung transplant</td>
</tr>
<tr>
<td>Post-cardiac surgery</td>
<td>Post-thoracic surgery</td>
</tr>
</tbody>
</table>
# Severity of Respiratory Failure

<table>
<thead>
<tr>
<th>CESAR Inclusion Criteria&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Modified Murray Lung Injury Score&lt;sup&gt;2&lt;/sup&gt;</th>
<th>EOLIA Inclusion Criteria&lt;sup&gt;3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>or Murray score &gt; 3</td>
<td>CXR quadrant consolidation</td>
<td>PaO&lt;sub&gt;2&lt;/sub&gt;/FiO&lt;sub&gt;2&lt;/sub&gt; &lt; 50</td>
</tr>
<tr>
<td>pH &lt; 7.2</td>
<td>PaO&lt;sub&gt;2&lt;/sub&gt;/FiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>for &gt; 3 hrs</td>
</tr>
<tr>
<td></td>
<td>PEEP</td>
<td>PaO&lt;sub&gt;2&lt;/sub&gt;/FiO&lt;sub&gt;2&lt;/sub&gt; &lt; 80</td>
</tr>
<tr>
<td></td>
<td>Respiratory system compliance</td>
<td>for &gt; 6 hrs</td>
</tr>
</tbody>
</table>

Despite maximal conventional therapy

<sup>1</sup>Peek et al. Lancet (2009) 374: 1351–63,  
## VV ECMO ARDS Outcomes

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<th>Study</th>
<th>Design</th>
<th>Table 1</th>
<th>Intervention (n)</th>
<th>Survival</th>
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<td>CESAR</td>
<td>RCT</td>
<td>P:F 75, PEEP 14</td>
<td>ECMO referred (90)</td>
<td>63%</td>
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<td></td>
<td></td>
<td>pH 7.1</td>
<td>Usual care (90)</td>
<td>47% (p = 0.03)</td>
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<td>Noah H1N1</td>
<td>Prosp. cohort</td>
<td>P:F 55</td>
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<td>76%</td>
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<td></td>
<td></td>
<td></td>
<td>Matched control (195)</td>
<td>50% (p &lt; 0.01)</td>
</tr>
<tr>
<td>EOLIA</td>
<td>RCT</td>
<td>P:F 72, PEEP 12</td>
<td>ECMO (124)</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pH 7.24</td>
<td>Usual care (125)</td>
<td>54% (p = 0.09)</td>
</tr>
</tbody>
</table>
## VA ECMO Outcomes

<table>
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<tr>
<th>Study</th>
<th>Design</th>
<th>n</th>
<th>Data Source</th>
<th>Etiology of shock</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorusso 2016</td>
<td>Cohort</td>
<td>57</td>
<td>13 centers Italy &amp; UK</td>
<td>Myocarditis</td>
<td>71.9%</td>
</tr>
<tr>
<td>Aso 2016</td>
<td>Cohort</td>
<td>4,658</td>
<td>&gt; 1k centers Japan</td>
<td>Ischemic 42.2%, ADHF 34.8%, valvular 13.7%, myocarditis 4%, cardiomyopathy 4.1%</td>
<td>26.4%</td>
</tr>
<tr>
<td>Truby 2015</td>
<td>Cohort</td>
<td>179</td>
<td>Single center New York City</td>
<td>Post-cardiotomy 39%, MI 26%, primary graft failure 10%, ADHF 13%</td>
<td>44.7%</td>
</tr>
<tr>
<td>Biancari 2018</td>
<td>Meta-analysis</td>
<td>2,986</td>
<td>31 studies International</td>
<td>Post-cardiotomy</td>
<td>36.1%</td>
</tr>
<tr>
<td>Meneveau 2018</td>
<td>Case series</td>
<td>52</td>
<td>9 centers France</td>
<td>Pulmonary embolism</td>
<td>39%</td>
</tr>
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*Acute decompensated heart failure (ADHF), myocardial infarction (MI)*
## ECLS Registry Report

International Summary

January, 2020

### Overall Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Total Runs</th>
<th>Survived ECLS</th>
<th>Survived to DC or Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary</td>
<td>24,395</td>
<td>16,971</td>
<td>69%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>25,488</td>
<td>15,184</td>
<td>59%</td>
</tr>
<tr>
<td>ECPR</td>
<td>8,075</td>
<td>3,363</td>
<td>41%</td>
</tr>
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</table>

**Highlighted:**
- Pulmonary: Survived to DC or Transfer = 60%
- Cardiac: Survived to DC or Transfer = 43%
- ECPR: Survived to DC or Transfer = 29%

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Extracorporeal cardiopulmonary resuscitation (ECPR)
Physiology
The Pump

Preload sensitive and afterload limited

Systemic vascular resistance (SVR), mean arterial pressure (MAP)

• Venous cannula resistance
• Blood volume
• Intra-thoracic pressure
• Intra-abdominal pressure

• Arterial cannula resistance
• Membrane lung resistance
• SVR & MAP (VA)

Preload sensitive and afterload limited

The Pump

Speed ➔ Flow

Preload ➔ Pump ➔ Afterload
Inadequate Pump Preload
The Membrane Lung

Blood

Gas

$F_dO_2$ & Sweep flow rate

$S_{postO_2}$

$S_{preO_2}$

© 2018 CollectedMed, LLC.
The Membrane Lung

Increase sweep flow rate to remove more $\text{CO}_2$
VV ECMO
VV Day 1

Steve is cannulated for VV ECMO

PC
Ppeak 14
RR 10
FiO2 40%
PEEP 10
Vt 150cc

Sweep: 3 L/min, FdO₂: 100%

How can we improve SpO₂?
Two circulations in series

- Sweep gas $\text{FdO}_2$
- $S_{\text{preO}}_2$ (saturation pre-membrane)
- Pump + Membrane lung
- $S_{\text{postO}}_2$ (saturation post-membrane)
- $S_{\text{O}_2}$ (arterial oxygen saturation)
- $\text{SpO}_2$
- $X$
- $\text{PEEP, F}_1\text{O}_2$
- Fraction delivered oxygen percentage ($\text{FdO}_2$)
ECMO blood flow $\rightarrow$ Oxygenation

VV Day 1

Steve is cannulated for VV ECMO

PC
Ppeak 14
RR 10
FiO2 40%
PEEP 10
Vt 150cc

Sweep: 3 L/min, FdO₂: 100%

Increase ECMO blood flow!

Pressure control ventilation (PC)
Recirculation

Recirculation Signs:
- Falling $S_pO_2$
- Rising $S_{pre}O_2$
- Both cannulas bright red

Treatment:
- Decrease speed
- Adjust cannula position

Abrams et al. ASAIO Journal 2015; 61:115–121

$O_2$ saturation of venous drainage cannula ($S_{VD}O_2$)
Check tubing color

Normal

Recirculation

Membrane lung failure
Normal Recirculation

10.9 cm apart

Recirculation

4.1 cm apart
VV ECMO Hypoxemia?

ECMO blood flow  Tubing color change  SpreO$_2$

saturation pre-membrane ($S_{pre-O_2}$)
VV Day 3

Adjust cannula position!
VA ECMO
VA Day 1

Sandy is cannulated for VA ECMO

How should we improve blood pressure?

Fraction delivered oxygen percentage (FdO₂)
VA ECMO Hemodynamics

\[
\text{MAP} = (Q \times \text{SVR}) + \text{RAP}
\]

MAP: mean arterial pressure
Q: flow
SVR: systemic vascular resistance
RAP: right atrial pressure
Total systemic blood flow = ECMO Flow + CO

Stevens et al. *J Biomech.* 2017;55:64-70
VA Day 1

Sandy is cannulated for VA ECMO

Increase ECMO blood flow!

Fraction delivered oxygen percentage (FdO₂)

Sweep: 2 L/min, FdO₂: 100%

HR: 130
Sat: 98%
BP: 72/51

0.3 mcg/kg/min Norepinephrine Bitartrate Injection, USP
10 mcg/kg/min DOBUTamine Injection, USP
0.08 mcg/kg/min Epinephrine Injection, USP
VA Day 4

- LVEF now 20% (was 10%)
- Ventilator starts alarming with increased peak pressure on volume control

How do you troubleshoot this?
Two circulations in parallel

Fraction delivered oxygen percentage ($F_dO_2$), saturation pre-membrane ($S_{preO_2}$), saturation post-membrane ($S_{postO_2}$)
Upper body hypoxemia

Regional gas exchange $\rightarrow$ differential oxygenation

Keep pulse oximeter on right upper extremity!
Hypoxemia on VA ECMO

- **Hypoxemia**
  - **Differential Hypoxemia**
    - yes: **Fix lungs?**
      - yes: **Continue VA**
      - no: **Decannulate**
    - no: **Membrane lung failure**
      - **Convert to VV**
  - **Bad heart**
  - **Recovered heart**

Venoarteriovenous (VAV)
VA Day 4

- LVEF now 20% (was 10%)
- Ventilator starts alarming with increased peak pressure on volume control

Fix lungs!

- Norepinephrine Bitartrate 0.04 mcg/kg/min
- Dobutamine Injection, USP 3 mcg/kg/min
Summary

• Drainage → pump → membrane lung (sweep) → return
• Cannulate only with discontinuation strategy
• Centrifugal pump pre-load dependent & afterload sensitive
• Increase sweep gas rate to decrease PaCO₂
• VV oxygenation improved with increased blood flow
• VV recirculation when PpreO₂ high and SpO₂ low
• VA ECMO flow + native cardiac output are additive
• Regionalized gas exchange in peripheral VA ECMO
Questions?

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VA ECMO
VV ECMO
Membrane Lung Failure

**Intrinsic**
- Microtubule dysfunction
- High delta P, clot
- Poor CO₂ or O₂ transfer on pre/post gas

**Sweep gas interruption**
- Acute
- Normal delta P
- Clear window

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<td>(p = 0.03)</td>
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<tr>
<td>ANZ H1N1</td>
<td>Obs.</td>
<td>P:F 56, PEEP 18 pH 7.2</td>
<td>ECMO (68)</td>
<td>79%</td>
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<td>JAMA 2009</td>
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<td>(p &lt; 0.01)</td>
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<td>Pham H1N1</td>
<td>Prosp. cohort</td>
<td>P:F 63, PEEP 13 pH 7.26</td>
<td>ECMO referred (123) Matched control (52)</td>
<td>65% for both</td>
</tr>
<tr>
<td>AJRCCM 2013</td>
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Oxygenation