Extracorporeal Life Support
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Objectives

• Discuss the physiology of ECMO
What is this ECLS (ECMO)?

- Extracorporeal membrane/hollow fiber lung and/or cardiac support.
- A support therapy, in no way definitive (sort of).
- 2 basic types:
  - Veno-arterial ECMO
  - Veno-venous arterial ECMO

Indications for ECMO

- Cardiac Failure Unresponsive to Traditional Therapies (post-op, cardiomyopathy, dysrhythmias)
- Respiratory Failure Unresponsive to Traditional Therapies (MAS, CDH, ARDS)
- CPR unresponsive to conventional efforts (ECPR)
- Potentially Reversible Underlying Disease.
Indications (cont’d)
Why ECMO?

• Simply a way to ensure (hopefully) adequate oxygen delivery
• Goal of limiting further injury to failing organs (lungs, heart, end organs).
Veno-arterial ECMO

- Blood is drained from a vein (usually the right atrium) and returned to the aorta.
- Provides both cardiac and pulmonary support as needed.
- Currently the support of choice for patients with cardiac failure (e.g., post-operative congenital cardiac disease, ECPR).

Venoarterial ECMO

- Full support: 80% of flow through circuit (non-central cannulation).
- Infants >100-120 cc/kg/minute
- Children/adults 2.5-4.0 L/M²/min
- Percent of flow made most obvious by arterial line tracing
Veno-Arterial ECLS - Configuration
Veno-venous ECMO

- Blood is drained from a vein and returned to a venous catheter.
- Drainage sites are dependent upon patient size and upon metabolic requirements.
- Double lumen cannula vs. multiple single lumen cannula.
Veno-venous ECMO

Veno-venous ECLS – Configuration
Recirculation

- Factors affecting recirculation:
  - Pump Flow
  - Catheter Position
  - Cardiac output
  - RA size (intravascular volume)

- Arterial saturations may be a lot lower than we wish
Idiosyncrasies of VV ECMO

- Pt require cardiac function
- If the lungs collapse completely, PVR rises
- This may result in RV dysfunction and with no intracardiac right-to-left shunt, cardiac output may fall.
Cardiac function & VV ECMO

Indirect cardiac support may occur via improved oxygenation of blood perfusing the coronaries

In a study of neonate, inotrope scores were followed before and after ECMO.

Roberts N et al. ASAIO J 2003; 49: 568
V-A vs V-V ECLS

**VA ECLS**
- Circulatory support
- \(\text{SaO}_2\) high (>95%) [Harlequin syndrome]
- \(\text{CO}_2\) removal: sweep gas flow & membrane size
- PAP lowered
- No recirculation
- \(\text{SvO}_2\): adequacy of \(\text{DO}_2\)

**VV ECLS**
- Indirect cardiac support
- \(\text{SaO}_2\) 80-95%
- Same
- PAP +/-
- Recirculation
- \(\text{SvO}_2\) may be deceptive.

V-A & V-V ECMO (similarities)

- Systemic anticoagulation/bleeding
- Surgical insertion of cannula (+/-)
- High transfusion requirements
- Risk of infection
- Sedation/ neuromuscular blockade requirements.
V-A & V-V ECMO (similarities)

- Pre-ECMO injury.
- Exposure to biomaterials.
- Activation of endothelial cells.
- Activation of coagulation pathways
- Activation of complement

V-A vs V-V ECLS

- An important difference between the two modes is the absence of the need to use a major artery.
- This decreases the danger from embolic events (clots or air).
- No VA vs VV study in randomized population
### Complication & ECMO Mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>CNS Comp</th>
<th>Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA</td>
<td>13.5%</td>
<td>52%</td>
</tr>
<tr>
<td>VV</td>
<td>7.0%</td>
<td>68%</td>
</tr>
<tr>
<td>OR</td>
<td>0.48</td>
<td>0.50</td>
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<tr>
<td></td>
<td>(0.34-0.67)</td>
<td>(0.41-0.61)</td>
</tr>
</tbody>
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Cengiz P et al. CCM 2005

### Basics of ECMO Physiology

- **Oxygen Delivery**
  - Cardiac output x Oxygen content (C.O. x CaO$_2$)

- **Oxygen content** = oxygen bound to hemoglobin + oxygen dissolved in plasma
  - CaO$_2$ = ([Hgb] x 1.34 x SaO$_2$) + (PaO$_2$ x 0.003)
Basics of ECMO Physiology

- Oxygen Delivery (V-A)
  - C.O. x CaO₂
  - C.O. = [HR X SV] + pump flow_{VA}
  - CaO₂ = [Hgb X 1.34 x SaO₂] + [PaO₂ x 0.003]

O₂ Delivery (V-V)
- (Pump flow mixes with SvO₂) – recirculation fraction.
RL

RV
LA
LV

Systemic Circulation

CvO$_2$ = 15 cc/dL
SvO$_2$ 76%

PvO$_2$ = 40 mmHg
Flow 2L/min

Circuit

RV
RA
LA
LV

CvO$_2$ = 17.3 cc/dL
SvO$_2$ 84%, PaO$_2$ 50 mmHg

Flow @ 3L/min.

Lung BF
CvO$_2$ 18.9 cc/dL
SpO$_2$ 94%

RV
RA
LA
LV

CvO$_2$ = 15 cc/dL
SvO$_2$ 76%

PvO$_2$ = 62 mmHg

Circuit

CvO$_2$ = 18.9 cc/dL
SvO$_2$ 94%, PaO$_2$ 62 mm Hg

Flow @ 2 L/min.
Lungs

Lung BF
CO₂ 18.5 cc/dL
SpO₂ 92%

PvO₂ = 60 mmHg
Flow 2.0 L/min

RV
RA
LA
LV
Aorta

CvO₂
14cc/dL
SvO₂ 72%

Systemic Circulation

Perfusate
CpaO₂ 16.9 cc/dL
SpO₂ 98%
PaO₂ 54
Flow 2L/min

Perfusate
CpaO₂ 22 cc/dL
SpO₂ 100%
PaO₂ 600
Flow 2L/min

Circuit

Frank-Starling Relationship

Preload

• Frank-Starling Relationship
Preload & the Pump

• Centrifugal pumps depend on preload as well
• Low preload may result in chattering, cutting out, sucking tissue into the cannula, decreased pump flow.

Cutting out

• Hypovolemia
• Cannula position
• VA
  – Arterial cannula
  – Venous cannula
• VV
• Abdominal compartment syndrome
Cutting Out

- Cardiac tamponade
  - Central venous pressure
- Abdominal pressure syndrome
- Cannula radius too small
  - Consider additional drainage

Afterload

- Force the ventricle must overcome to eject blood
- Complex
  - Wall stress \(p \times \frac{r}{2h}\)
  - Vascular resistance
  - Valvular stenosis
  - Inertia of blood
ECMO Pump

- Centrifugal pumps are also sensitive to afterload
- High BP or high SVR can decrease pump output per given RPM.

ECMO pump/heart interactions

- VA ECMO influences both cardiac preload and afterload
- By removing blood from large veins/RA preload to both ventricles is decreased.
- However, cannula placement in the aorta may cause an increase in afterload
ECMO/heart/ventilator interactions

- Decreasing support on the ventilator may decrease right ventricular afterload
- But, may increase left ventricular afterload
- So the ultimate effect of ECMO on heart function and cardiac output depends.

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ECMO/heart/ventilator interactions

- When the LV does not eject, even with excellent venous drainage blood can continue to return to the left atrium.
- This can result in over distension of the LV
- With possible pulmonary edema, hemorrhage, and death
- Left side must be vented or
- Atrial septostomy
Harlequin syndrome - VA

- Femoral arterial cannulation
- Heart function returns before lung failure abates
- LV ejects desaturated blood
- Mixes with the ascending oxygenated blood
- May expose brain to poor oxygenation

Complications
Post-ECMO change in CO₂


Hypertension: Considerations

- VA-nonpulsatile flow
- Fluid status
- Elevated plasma free hemoglobin
- Corticosteroids
- Neurologic catastrophe
VA-nonpulsatile flow

- Complications
  - Hypertension
  - Renal dysfunction: anti-diuretic
  - At low flow, shock is more likely with non-pulsatile flow.
  - Results in greater stimulation of the aortic and carotid body baroreceptors with increased sympathetic outflow.

Cost of Complications: Fluid overload

Selewski DT et al. CCM 2012; 40:2694
Fluid Overload Trumps Fluid Removal

Selewski DT et al. CCM 2012; 40:2694

Renal Complications - Neonates
Renal Complications - Children

Complications -

• Thrombosis

Bleeding
Hemostasis

- The endothelium maintains the fluidity of the blood as well as the integrity of the vascular system.
- When blood contacts any other surface coagulation is initiated.

Platelet consumption

![Platelet consumption graph](image-url)
Alternatives to Heparin

F is for Fanny sucked dry by a leech
Alternatives to Heparin

• Lepirudin – leech extract.
• Argatroban – direct thrombin inhibitor.  
  Does not require ATIII.
• Citrate has not been commonly used as the anti-coagulant in ECMO

Heparin

• Heparin interacts with many proteins, binding positively charged proteins
• Longterm use can result in osteopenia and fractures
• Osteopenia worsened by prolonged bed rest
**VA Weaning ECMO**

- When patients are placed on VA ECMO for cardiac failure, pump flows are often lowered slowly.
- This permits the heart to gradually assume more of the load of cardiac output.
- Trials off ECMO require clamping of the tubing.

**Weaning VV ECMO**

- Improvement of lung function often accompanied by improvement in CXR, increased air movement with less ventilator support.
- Weaning of flows not necessary.
- Can wean by lowering sweep gas.
- Discontinuing gas source will discontinue ECLS support.
Weaning VA ECMO

- In the face of cardiac failure, unloading the heart may induce deconditioning.
- Slow weaning of pump flow may be required to retrain myocardium.
- Discontinuing ECMO support requires clamping of the cannula.
- Attention must be paid to clots in cannula/tubing.

N is for Neville who died of ennui.