ECMO Physiology
Disclosures

- No disclosures
Physiology of ECLS Gas Exchange

Oxygen Kinetics
Blood Flow and Hb
Membrane Lung Function
Membrane Lung Pathophysiology
**O₂ KINETICS**

- **VO₂**: 120 cc

- **AVDO₂**: Cₐ - Cᵥ

- **3L®** Cardiac Index

- **O₂ Delivery**: SOD₂ DO₂

- **REE** (calories) = 5 cal/L VO₂

- Direct Measure
  - or
  - AVDO₂ × CO

- CO

- **Satₐ** = 100

- **Satᵥ** = 80

- **Cᵥ**

- **600 cc** = 5

- **120 cc** = 1

- **DO₂/VO₂** Coefficient of O₂ Delivery

- **m** = /min/m₂
O₂ content cc/dl = Hb gm/dl x sat x 1.36 + PO₂ x 0.003
OXYGEN DELIVERY

$O_2$ delivered to tissues per minute

$CaO_2 \times C.O. \times 10$

Example: $CaO_2 = 18 \text{ ml/dl}$  
$C.O. = 5 \text{ L/min}$  
$DO_2 = 900 \text{ ml/min}$
DO₂/VO₂ Ratio

Normal - 5:1 80%

Critical low point - 2:1 50%

Ischemia, shock, Supply dependency = < 2:1

Ischemia time/dose can be quantitated
OXYGEN CONSUMPTION/DELIVERY AND SHOCK

DO$_2$/VO$_2$ Ratio: 2  3  4  5
O$_2$ Extraction Ratio: .5  .33  .25  .2
V Sat: 50  66  75  80
(if Sa = 100)

VO$_2$ cc m

Gas volumes STPD

DO$_2$ cc c
INTERPRETING THE DO₂/VO₂ DIAGRAM

Metabolism

Hyper

Normal

Hypo

O₂ Delivery Reserves

SHOCK

Normal

Excess Perfusion and AV Fistula

Oxygen Delivery
Gas exchange with membrane lungs

- Oxygenation: controlled by
  1. Amount of O2 that can be added to inlet blood
     - Hb, Sat, dissolved O2 (O2 content)
  2. Blood flow
  3. Surface area and secondary flows
  4. Rated flow
  5. FiO2 in ventilating gas

- CO2: controlled by
  1. Sweep gas flow
  2. Percent of CO2 in sweep gas
  3. Surface area
O2 to Blood
Across Lung or Membrane Lung

A-V or Outlet – Inlet O2 Content difference
Dependent on Hb, venous (inlet) O2 content

Examples. At FiO2 1.0

<table>
<thead>
<tr>
<th>Hb</th>
<th>V Sat</th>
<th>C,O2in</th>
<th>C,O2out</th>
<th>HBavailable</th>
</tr>
</thead>
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<tr>
<td>15</td>
<td>73</td>
<td>15</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>gm</td>
<td></td>
<td>21.9</td>
<td>6.9cc/dL</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>60</td>
<td>12.2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>gm</td>
<td></td>
<td>21.9</td>
<td>9.7 cc/d</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>75</td>
<td>10.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Outlet (arterial) saturation

Inlet (venous) saturation

Hb % saturation

O₂ Delivery cc/min

O₂ delivery

Maximum O₂ delivery for Δ A-V 5 vol.%

Actual O₂ delivery

Rated Flow: 3 L/min
Oxygen Transfer

Data points:
- QUADROX-i Adult
- QUADROX-i Adult with integrated arterial filter

Oxygen transfer vs. blood flow (l/min)

Quadrox D
Rated flow/ O2 transfer
Carbon Dioxide Transfer

CO₂ Transfer · ml/min

gas/blood flow ratio
- 2:1
- 1:1
- 0.5:1

QuadroxD
CO₂ transfer

blood flow l/min
O2 Delivery From Membrane Lung

ECMO Flow

Outlet-Inlet O2 Content (cc/dL)
Mixing 2 Blood Flows of Different O2 Content

The resultant O2 content is the sum of the O2 content x flow for each flow
(roughly the sum of the sat x flow for each flow)

\[
C_1 \times \frac{\text{Flow}_1}{\text{Total flow}} + C_2 \times \frac{\text{Flow}_2}{\text{Total flow}} = C_3 \\
\text{Total flow} \quad \text{Total flow}
\]

OR

\[
S_1 \times \frac{\text{Flow}_1}{\text{Total flow}} + S_2 \times \frac{\text{Flow}_2}{\text{Total flow}} = S_3 \\
\text{Total flow} \quad \text{Total flow}
\]
Calculating Cardiac Output from the mixing equation

Total Flow = \( \text{flow}_1 \frac{(S_1 - S_2)}{S_3 - S_2} \)

Cardiac output = \( 3(100-70) \times \frac{85-70}{85-70} \) = 6L/min

when \( S_1 = 100 \)
\( S_2 = 70 \)
\( S_3 = 85 \)
\( \text{flow}_1 = 3 \) L/min
Mixing Two Flows With Different SO2

A=ECC, B=Venous, A+B=CO

SO2 of Flow A + B

SO2 of Flow B

Ratio of Flow A to B Assuming Flow A (SO2=100%)
ECMO Gas Exchange: Summary

- Oxygenation:
  - Goal is DO2 > 4X Oxygen consumption
  - O2 Delivery controlled by FLOW, HB, INLET SAT
  - Outlet sat > 100% up to rated flow

- CO2 removal:
  - Goal pCO2 40-45
  - Controlled by sweep gas flow rate
Physiology of ECLS
Hemodynamics

- Vascular access
- VA physiology (Cardiopulmonary Bypass)
  Artificial lung in parallel
- VV physiology (respiratory support only)
  Artificial lung in series
Management with VA, VV, AV, VVA
VA: Venoarterial access via the neck vessels
VA: Venoarterial access via the femoral vessels
VAV: Venoarterial access with some venous RA return
Veno-venous ECLS with a double lumen cannula
VENOVOUS BYPASS

ADVANTAGES
- Pulmonary circulation is maintained. Pulmonary circulation oxygenation is maintained
- Particulate emboli travel to lungs
- No carotid ligation
- Pulsatile arterial waveform maintained
- Efficient CO₂ removal

DISADVANTAGES
- No control of blood pressure
- Inefficiency (recirculation). Hypoxemia (low pO₂'s)
- Dual site access (jugulofemoral access) vs. double lumen catheter single site access
Bi-caval Dual Lumen Catheter
Novalung Membrane Lung

Low blood flow is enough to remove CO2
Can be AV (shown here) or VV
Can be any oxygenator
Control of Physiologic Variable with ECLS

Metabolism (VO2): temperature

Oxygen supply via membrane lung:
- Hb, A-V content difference, pump flow

Oxygen Delivery to tissues (DO2): Ca O2 x blood flow

CO2 clearance (VCO2): Minute ventilation to membrane lung

Blood flow: Cardiac output in VV, Pump flow + CO in VA

Arterial blood Pressure: Blood flow in VA, Hct