Introduction to ECMO

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United Critical Care Lung and Sleep Medicine
I HAVE NOTHING TO DISCLOSE!
BEFORE ECMO

SOME WORLD HISTORY AND TRIP AROUND THE GLOBE
Tordesillas Treaty-1494
Age of Discovery

• Henry The Navigator (Infante Dom Henrique) - 1394-1460
  • -King John I: Duarte, Pedro, Henrique

• Columbus: 1492-1502
  • -Vasco Da Gama (1497-1499) - sea route to India

• -Pedro Alvares Cabral (1500) - Brazil

• -Fernão de Magalhães (1519-1522) - around the world
Torre De Belém
Guinea-Bissau
1456
Tomar-Portugal-Order of Templars
Hospital De Santa Maria-Lisbon
Egas Moniz

FRONTAL LOBE LOBOTOMY-1935

NOBEL PRIZE MEDICINE-1945

ROSEMARY KENNEDY-LOBOTOMY(1941)
New York Hospital-Cornell
Memorial Sloan-Kettering Cancer Center
Stony Brook University Hospital
The Alfred, Melbourne - Australia
Oh yes, please tell me how hard your job is.
Introduction to ECMO

- 1-History
- 2-Current status
- 3-Membrane Gas Exchange
- 4-Oxygen Content, Delivery and Consumption
Acknowledgement

• Dr Robert Bartlett, MD, Michigan ECMO

• Dr Steven Conrad, MD, LSU Health Sciences Center
HISTORY OF ECMO AND CURRENT STATUS
History and Development of Extracorporeal Life Support

- 1667-Jean Baptiste Denys: Cross-transfusion of blood of a human with the “gentle humors” of a lamb, to determine if living blood could be transmitted between 2 species.

- (Antoine Mauroy)

- 1860-Benjamin Ward Richardson: Injected O2 plus blood via a syringe to the RV to generate artificial circulation in an animal model.
• 1931- John and Mali Gibbon
  - Developed first CPB machine

• 1934-Debakey: Design of dual roller pump system

• 1953- John Gibbon
  - ASD repair on CPB (18 y/o patient)
First Cardiopulmonary Bypass Machine
Debakey

Roller Pump

Simultaneous adjustments
the rollers

Silicone tube

Occlusion

150.0 mm
OXYGENATOR (Late 1950’s, Early 1960’s)

- 1-Phil Drinker, Robert Bartlett (Boston Children’s Hospital)
- 2-Theodor Kolobow (NIH)
- 3-J.D. Hill (San Francisco)
- 1968: P Drinker & Robert Bartlett: canines on ECMO
1971: Dr J.D Hill:
- ECMO outside the OR
- 24 y/o male with rupture aorta, post MVC: VA ECMO x 72 hours-survived

1972: Bartlett & Gazzaniga:
- First Pediatric cardiology case
- Mustard procedure in 12 year old- ECMO x 30 hours
• 1975-Robert Bartlett
• -First Neonatal case
• Baby Esperanza: 72 hours
• Esperanza at 21
Trials

- 1993-1995
  - UK trial for neonates: mortality-ECMO 30/93; conventional 54/92

1994: VA vs standard care-no difference

2001-2006: UK-Cesar trial (Giles Peek): VV ECMO for adults with respiratory failure; survival-ECMO 57/90; conventional 41/87

2009: H1N1

2018: EOLIA trial: ECMO mortality-35%; Conventional-46%
• 1989- First ELSO meeting
• 1991-EuroELSO
• 2012-LAELSO
• 2014: APELSO
• 2013: South & West Asia ELSO
<table>
<thead>
<tr>
<th>Years</th>
<th>Chair</th>
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<tbody>
<tr>
<td><strong>ELSO</strong></td>
<td></td>
</tr>
<tr>
<td>2016-2018</td>
<td>Michael McMullan</td>
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<tr>
<td>2014-2016</td>
<td>James Fortenberry</td>
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<tr>
<td>2012-2014</td>
<td>William Lynch</td>
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<tr>
<td>2010-2012</td>
<td>Steve Conrad</td>
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<tr>
<td>2007-2010</td>
<td>Mike Hines</td>
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<tr>
<td>2004-2007</td>
<td>Heidi Dalton</td>
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<tr>
<td>2002-2004</td>
<td>Joseph Zwischenberger</td>
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<tr>
<td>2000-2002</td>
<td>Ronald Hirschel</td>
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<tr>
<td>1997-2000</td>
<td>Charles Stolar</td>
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<tr>
<td>1994-1997</td>
<td>Michael Klein</td>
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<tr>
<td>1993-1994</td>
<td>Billie Lou Short</td>
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<tr>
<td>1989-1993</td>
<td>Robert Bartlett</td>
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<tr>
<td><strong>Euro ELSO</strong></td>
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<tr>
<td>2014-2017</td>
<td>Roberto Lorusso</td>
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<tr>
<td>2012-2014</td>
<td>Giles Peek</td>
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<td><strong>Asia Pacific ELSO</strong></td>
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<td>2013-2017</td>
<td>Graeme MacLaren</td>
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<td><strong>Latin American ELSO</strong></td>
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<tr>
<td>2015-2017</td>
<td>Luiz Caneo</td>
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<tr>
<td>2013-2015</td>
<td>Rodrigo Diaz/Javier Kattan</td>
</tr>
<tr>
<td></td>
<td>(Co-chairs)</td>
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<tr>
<td><strong>South and West Asia ELSO</strong></td>
<td></td>
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<tr>
<td>2018</td>
<td>Venkat Goyal</td>
</tr>
<tr>
<td>2017</td>
<td>Malaika Mendonca</td>
</tr>
<tr>
<td>2014 -2016</td>
<td>Suneel Poobani</td>
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</table>
## Overall Outcomes

<table>
<thead>
<tr>
<th></th>
<th>Total Runs</th>
<th>Survived ECLS</th>
<th>Survived to DIC or Transfer</th>
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<tbody>
<tr>
<td>Neonatal</td>
<td></td>
<td></td>
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<tr>
<td>Pulmonary</td>
<td>29,942</td>
<td>25,205</td>
<td>84% 21,948 73%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>7,109</td>
<td>4,643</td>
<td>64% 2,008 40%</td>
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<tr>
<td>ECMR</td>
<td>1,532</td>
<td>1,028</td>
<td>67% 627 40%</td>
</tr>
<tr>
<td>Pediatric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary</td>
<td>8,070</td>
<td>5,424</td>
<td>67% 4,632 57%</td>
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<tr>
<td>Cardiac</td>
<td>9,362</td>
<td>6,404</td>
<td>68% 4,758 50%</td>
</tr>
<tr>
<td>ECMR</td>
<td>3,399</td>
<td>1,958</td>
<td>57% 1,414 41%</td>
</tr>
<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary</td>
<td>12,346</td>
<td>8,242</td>
<td>66% 7,157 57%</td>
</tr>
<tr>
<td>Cardiac</td>
<td>10,982</td>
<td>6,251</td>
<td>56% 4,466 40%</td>
</tr>
<tr>
<td>ECMR</td>
<td>3,485</td>
<td>1,382</td>
<td>39% 993 28%</td>
</tr>
<tr>
<td>Total</td>
<td>86,287</td>
<td>60,537</td>
<td>70% 48,933 56%</td>
</tr>
</tbody>
</table>

## Centers

![Graph showing number of centers over time.]

**NOTE:**

- **CURRENT STATUS**
Present-day Intensivists, Surgeons, ICU Nurses face similar uncertainty in how to titrate support for ECMO as was confronted with the introduction of mechanical ventilation.

Lacking extensive animal data to inform practice, current ECMO demands that the health care providers applies physiologic principles to determine and guide support.
CARDIOPULMONARY PHYSIOLOGY
OXYGEN CONTENT, DELIVERY, CONSUMPTION AND EXTRACTION RATIO
CardioPulmonary Physiology

- All tissues of the body function by:
  - combining substrates with oxygen, producing heat, energy, CO2, and water - metabolism

- D02: oxygen delivered per minute

- V02: measurement of oxygen consumed per minute
  - adults: 3cc/kg/mn
  - children: 4cc/kg/mn
  - infants: 5cc/kg/mn
CardioPulmonary Physiology and Gas Exchange
- Native Circulation

- **A-Oxygenation**
- Oxygen partial pressure in the Oropharynx (159 mmHg)
- Alveolar (100 mmHg)
- Capillaries (90-95 mmHg) - venous mixture from returning systemic circulation
- Tissue capillaries - aerobic metabolism - \( P_{vO2} = 40 \text{ mmHg} \) (75%)
- SV02 (75%)
- ScV02 (upper body) - 5-10% higher
Partial Pressures of Gases Vary throughout the Human Circulatory System

- **Tissues**
  - $P_{O_2} < 40$ mm Hg
  - $P_{CO_2} > 45$ mm Hg

- **Blood entering tissue capillaries**
  - $P_{O_2} 140$ mm Hg
  - $P_{CO_2} 40$ mm Hg

- **Blood entering alveolar capillaries**
  - $P_{O_2} 40$ mm Hg
  - $P_{CO_2} 45$ mm Hg

- **Blood leaving alveolar capillaries**
  - $P_{O_2} 104$ mm Hg
  - $P_{CO_2} 40$ mm Hg

- **Inhaled air**
  - $P_{O_2} 160$ mm Hg
  - $P_{CO_2} 0.3$ mm Hg

- **Exhaled air**
  - $P_{O_2} 120$ mm Hg
  - $P_{CO_2} 27$ mm Hg

**Systemic circulation**
- **Blood leaving veins**
  - $P_{O_2} 40$ mm Hg
  - $P_{CO_2} 45$ mm Hg

**Pulmonary circulation**
- **Blood entering alveolar capillaries**
  - $P_{O_2} 104$ mm Hg
  - $P_{CO_2} 40$ mm Hg

**Alveoli of lungs**
- $P_{O_2} 104$ mm Hg
- $P_{CO_2} 40$ mm Hg

**Aorta**
- **Pulmonary artery**
- **Pulmonary vein**

**Venae cavae**
OXYGEN

• Oxygen is used in the Mitochondria for substrate oxidation, leading to production of energy and Carbon Dioxide.

• \((p_{02\,\text{INS}}) = \text{FI}02 \times p_B\)

• \((p_{02\,\text{ALV}}) < (p_{02\,\text{INS}})\): added water vapor and the balance between \(O_2\) removal by pulmonary capillaries and \(O_2\) replacement by alveolar ventilation.
Oxygen cascade from lung to tissue

"Oxygen Cascade"

But it doesn’t end there

PO$_2$ mm Hg

Sea Level

Air

Lung

Artery

Vein

40

6700 m

4540 m

80

120

160

Saturation

Pao$_2$

Capillary

Red cell

Pa$_2$

5.3

7

10

13

Diffusion distance

Pressure gradient

10/2.7 = 3.7 kPa

Pressure gradient

7.0 - 1.3 = 5.7 kPa

Mitochondria

PO$_2$ 0.7 - 1.3

Intracellular

PO$_2$ 2.7

Interstitial

PO$_2$ 2.7

PO$_2$ 5.3

Interstitial

PO$_2$ 1.3

Intracellular
• Oxygen Content and Hemoglobin
  • \(-\text{CaO}_2/\text{CvO}_2\)
  • Aggregate of \(2\) bound to Hb\((98.5\%)\)
  • mL/dL
• Primary determinant of \(2\) content: Hb concentration
• 1g Hb-binds 1.34 ml \(2\)
• 0.003ml/dL: solubility coefficient of oxygen in plasma
Arterial and Venous Oxygen Content

• **Equation 1**

  • CaO2 = (1.34 x Hb x O2 Sat) + (PaO2 x 0.003);  Hb=15 Sat 100%  P02 90
  • -CaO2 = 20g/dL

  • CvO2 = (1.34 x Hb x O2 Sat) + (PvO2 x 0.003);  Hb=15 Sat-75%  P02-40
  • -CvO2 = 15g/dL
Oxygen Delivery and Oxygen Consumption

• Equation 2
• $D_{O2} = CO \times CaO2 \times 10 = 5L/mn \times 20mL \times 10 = 1000mL/mn$

• Equation 3
• $V_{O2} = CO \times (CaO2 - CvO2) \times 10 = 5L/mn \times (20 - 15)mL/dL \times 10 = 250mL/mn$

• $-D_{O2}/V_{O2} = 5:1 - 4:1$ OR $OER(V_{O2}/D_{O2}) = 20\%-25\%$
• Oxygen Extraction Ratio = $20\%-25\%$
• **B-Co2 transfer**: 1-dissolved in plasma (10%); bound to Hb (30%); carried as bicarbonate (60%)

• $\text{PaCO}_2=40\text{mmHg}$ \hspace{1em} $\text{PV}_2=46\text{mmHg}$

• Ambient air $\text{PCO}_2=0.3\text{mmHg}$

• **Equation 4**

• Respiratory Exchange Ratio: $\text{VCO}_2/\text{V}_2$
MEMBRANE GAS EXCHANGE PHYSICS AND PHYSIOLOGY

OXYGEN CONTENT, DELIVERY AND CONSUMPTION
Membrane Gas Exchange Physics and Physiology

• Gas Exchange Devices (GED):
  - Gas exchange by perfusing venous blood through a network of thousands of small hollow fibers
  - The tubes are filled with continuously flowing gas (SGF) while blood flows exterior to the fibers

- Add O2 and remove CO2
- P02 = 40 mmHg; PC02 = 45 mmHg

- Rated Flow: The blood flow rate at which venous blood with saturation of 75% and Hb of 12 gm/dL will exit the GED with a saturation of 95%
Membrane Gas Exchange Oxygen Delivery

• 02 Delivery
• -Max 02 delivery of a GED: amount of 02 delivered per minute when running at rated flow
• -Difference between outlet-inlet blood=4-5cc/dL

• -Ex: 1-rated flow of 2.0L/mn:max 02 delivery
• -2.0L/mn(20dL/mn) x 5cc/dL=100cc/mn
• 2-4L/mn=200cc/mn
Oxygen Content, Delivery and Consumption - Membrane Gas

- \( \text{CaO}_2(\text{cc/dL}) = 1.34 \times \text{Hb (gm/dL)} \times \text{sat} + \text{P0}_2(\text{mmHg}) \times 0.003 \text{cc/dL/mmHg} \)

- \( \text{CvO}_2 = 1.34 \times \text{Hb} \times \text{sat} + \text{P0}_2 \times 0.003 \text{cc/dL} \)

- \( \text{D0}_2(\text{cc/mn}) = \text{C0}_2(\text{cc/dL}) \times \text{CO (L/mn)} \times 10 \)

- \( \text{V0}_2 = (\text{CaO}_2 - \text{CvO}_2) \times \text{CO} \times 10 \)

- \( \text{D0}_2/\text{V0}_2 - 5:1 \) OR \( \text{OER(VO}_2/\text{D0}_2) - 20\% \); lowest tolerated: 2:1 OR 50\%
Normal DO2/VO2 = 5:1. DO2/VO2 below 2:1 = shock
Oxygen in blood

O$_2$ Content vs. PO$_2$ and SAT

- **V** for Vein
- **A** for Artery

- Hb15
- Hb10
- Hb7.5
- Hb0

PO$_2$: 25 50 75 100 150 600
SAT: 50 75 90 99 100

O$_2$ Content cc/dl
Oxygen in blood

Arterial C O2 = 11.7 cc/dL
Venous C O2 = 5.36 cc/dL
AV DO2 = 6.34 cc/dL

Oxygen content = Hb gm/dL x % sat x 1.34cc/gm = ccO2/dL
Membrane Gas Exchange C02 Removal

- Sweep Gas
- Gas ventilated through the GED
- Usually 100% O2
- When mixing O2 with Room Air—O2/air blender
- Carbogen gas: 5% CO2/95% O2
- Rate: start 1:1-adjust rate to pCO2(36-44mmHg)
Membrane Gas Exchange: C02 Removal

Increasing SGF: decreases C02 but won’t affect 02

Water vapor can condense within the gas compartment of the membrane lung and can be cleared by intermittently increasing SGF to higher rate (otherwise, C02 may increase)

Membrane gas exchanger: clears C02 > adding 02