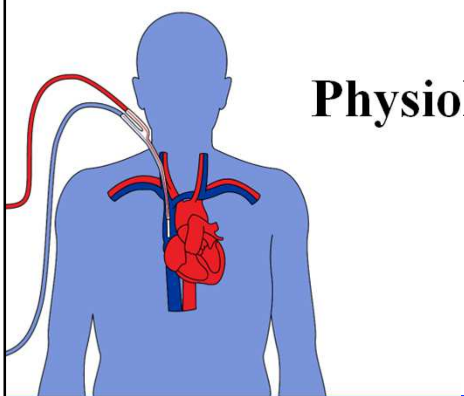


# ECMO:
# Physiology and Native Gas Exchange



1

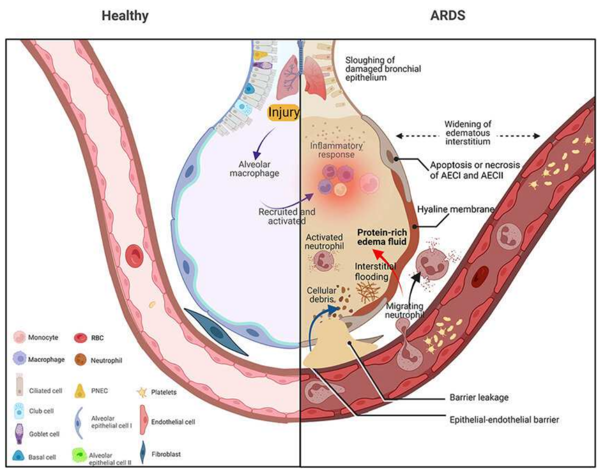
## Native Gas Exchange

- The alveolar level
- The tissue level



2

# Gas exchange at the Alveolar level




Cao et al., 2022



3

# Alveolar Air Equation

- $PAO_2$ = Inspired oxygen – Oxygen consumed

$$PAO_2 = FiO_2 (P_B - P_{H2O}) - (PaCO_2 \text{ x } R)$$

or

$$PAO_2 = FiO_2 (P_B - P_{H2O}) - \left(\frac{PaCO_2}{R}\right)$$

$P_B$ at sea level = 760 mmHg

$P_{H2O}$ = 47 mmHg at normal body temperature (37° C)

R = 1.25 if multiplying or 0.8 if dividing



4

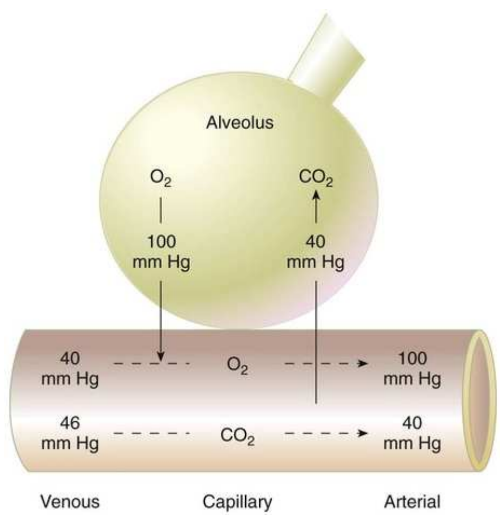
# PAO2

$$PAO_2 = FiO_2\ (760\text{-}47) - (PaCO_2 \times 1.25)$$
$$PAO_2 = 0.21\ (760\text{-}47) - (40 \times 1.25)$$
$$PAO_2 = 0.21\ (713) - 50$$
$$PAO_2 = 149.73 - 50$$
$$\boldsymbol{PAO_2 = 99.73\ mm\ Hg}$$



5

# Alveolar Gas Exchange




https://thoracickey.com/gas-exchange-and-transport/



6

## So….Why $PAO_2$??

- The job of the alveoli is to bring the blood and air together in such a way that **the alveolar oxygen ($PAO_2$) and the arterial oxygen ($PaO_2$) come to an equilibrium with each other.**



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## Alveolar-Arterial Oxygen *Difference*

- Example:
  - In a normal healthy young adult who is breathing room air, the $PAO_2$ should be ~100 mm Hg.
  - A normal $PaO_2$ for the same patient might be ~96 mm Hg. Thus the A-a $O_2$ difference would be:

100-96 = 4 mm Hg



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# Alveolar-Arterial Oxygen Gradient

- If the patient is on an $FiO_2$ of 100%, the A-a gradient should not exceed **65 mm Hg.**
- When a patient is on an $FIO_2$ of 100%- every 50 mm Hg difference approximates a 2% shunt.

ECMO Advantage



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# Hypoxemic MICU Patient

MICU ARDS patient on 4cc/kg Vt (IBW)

- AC/VC: 320/16 x 30 100%
- On 100% FIO2 at sea level our ABG is: 62/55/7.28
- Our $PAO_2$ = 1 (760-47) – (55 x 1.25) = 644

ECMO Advantage



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## Severe Hypoxemia

- A-a= 644 - 62 = 582
- 582÷50 (every 50 mmHg = 2% shunt).
- 11.64 x 2 = ***23.29%*** shunt



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## P/F Ratio

Berlin Criteria

- P/F 201-300 mm Hg **MILD**
- P/F 101-200 mm Hg **MODERATE**
- P/F ≤ 100 mm Hg **SEVERE**



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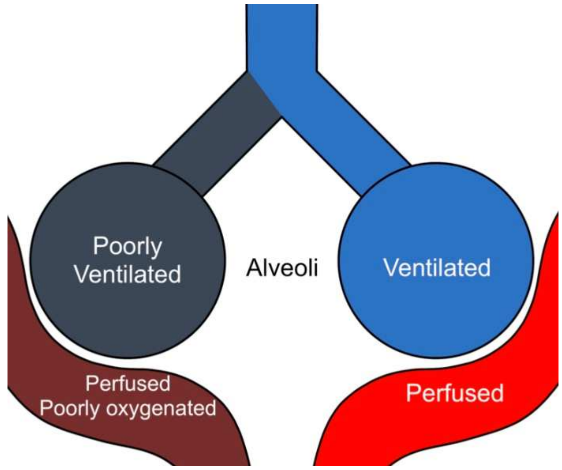
# Pulmonary Shunting




https://en.wikipedia.org/wiki/Ventilation%E2%80%93perfusion_coupling



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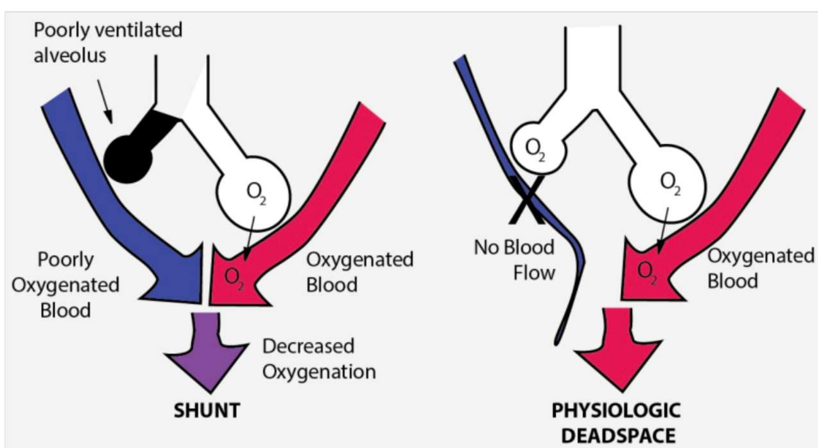
# V/Q Mismatch

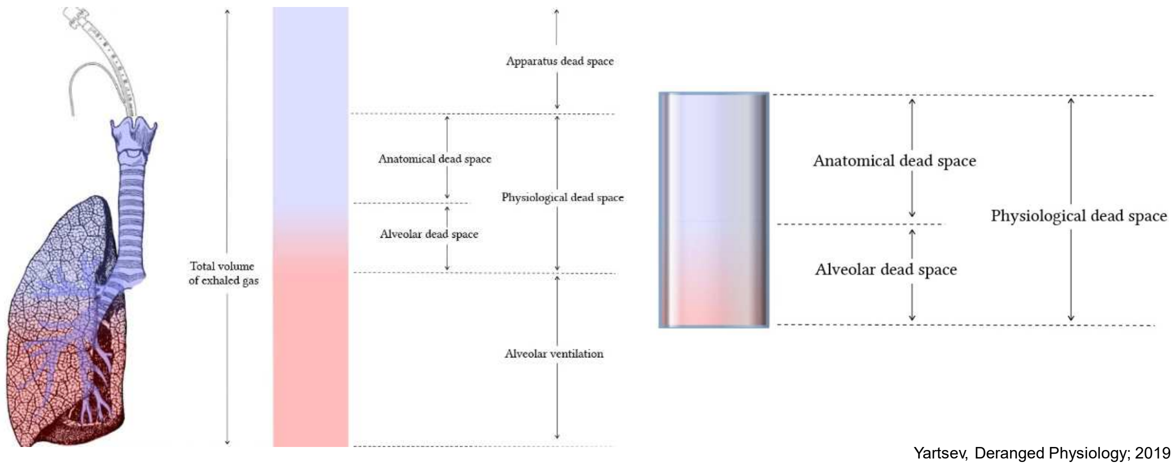



Whitten, The Airway Jedi; 2017



14

# Physiologic Dead Space




Yartsev, Deranged Physiology; 2019



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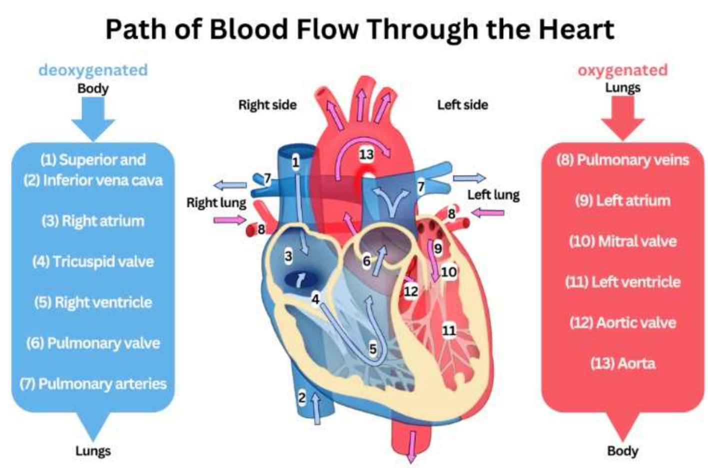
# Blood Flow Through the Heart




https://sciencenotes.org/path-of-blood-through-the-heart/



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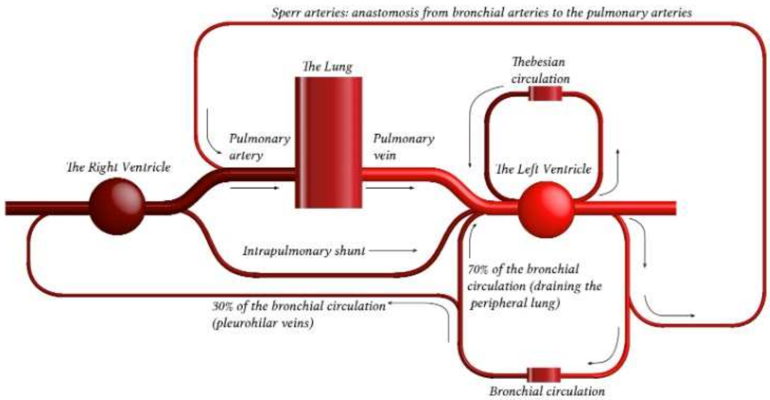
# Bronchial and Thebesian Circulation




Yartsev, Deranged Physiology; 2015



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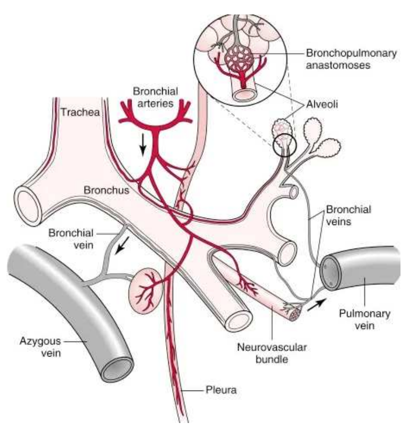
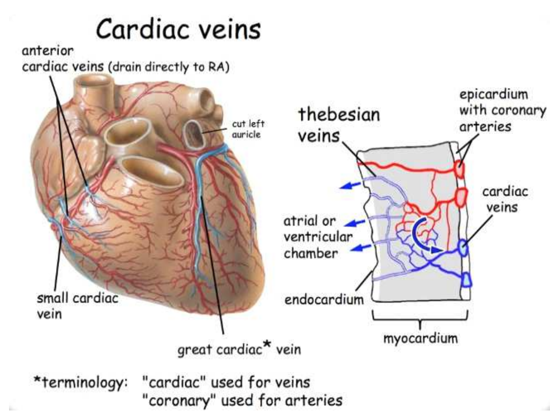
# Bronchial Veins




https://inspiredpencil.com/pictures-2023/bronchial-circulation

# Thebesian Veins




https://www.pinterest.com/pin/52495151891969228/



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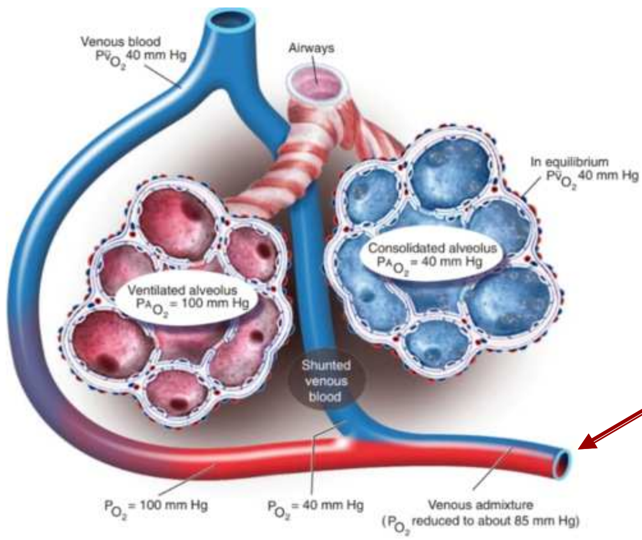


# Venous Admixture

https://quizlet.com/548374828/ventilation-perfusion-relationships-flash-cards/



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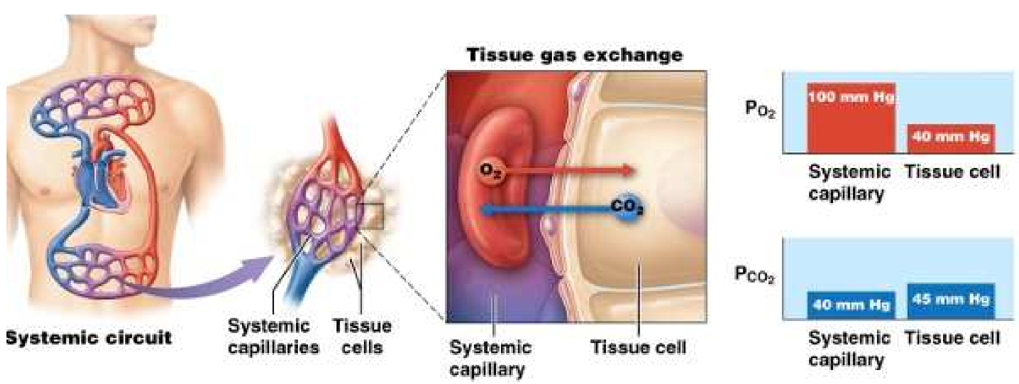
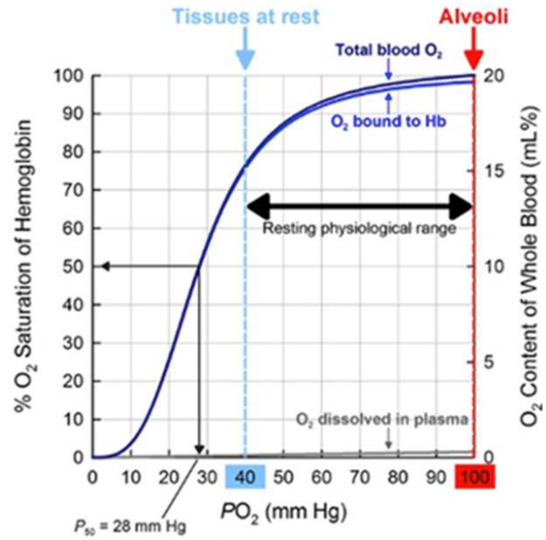
# Gas Exchange at the Tissue Level




//efaidnbmnnnibpcajpcglclefindmkaj/https://www.mccc.edu/~falkowl/documents/RespiratorySystem.pdf



20




https://www.physiologyweb.com/figures/physiology_graph_sLCVoxW1Ww7uMYapMyDLnHYZN5gCKV8v_oxyhemoglobin_dissociation_curve.html

# Oxyhemoglobin Dissociation Curve

The oxygen-hemoglobin dissociation curve is a plot of percent saturation of hemoglobin as a function of the partial pressure of oxygen (PaO2)



21

https://www.marineinsight.com/cruise/what-is-code-oscar-in-cruising-industry/

# Oxygen & Hemoglobin

https://longreads.com/tag/seinfeld/



22

# Time for ECMO…

https://gifdb.com/gif/amazed-the-rock-applause-yqzl1kebgirijfvn.html



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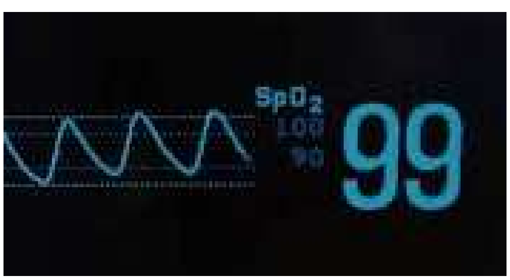
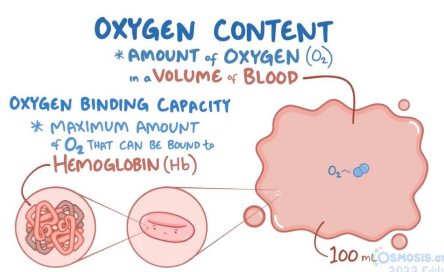
# Concepts…SpO2 vs CaO2




https://www.osmosis.org/notes/Gas_Transport



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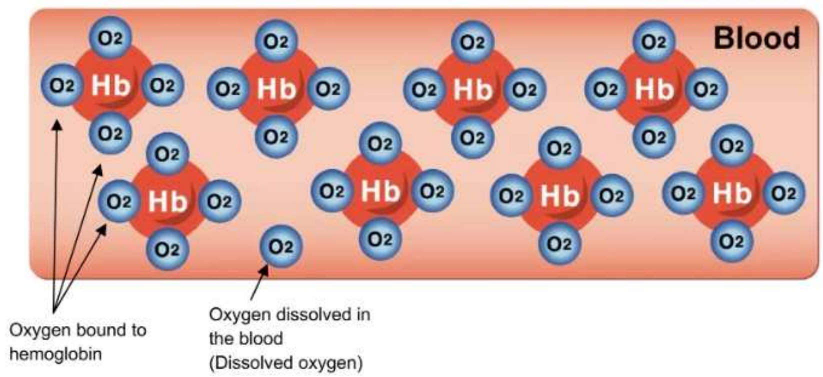
# Oxygen Content

**CaO2**
**CvO2**




https://www.slideshare.net/slideshow/about-pulseoximetry/4414385



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# CaO2

**CaO2 = (Hgb x 1.34 x SaO2) + (PaO2 x 0.003)**

Bound to Hemoglobin

Dissolved in plasma

- 1 gm of hemoglobin fully saturated carries 1.34 ml O2
- 0.003 is the solubility coefficient of O2 in the plasma



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# Who would you rather be?

- Hgb = **12**
- SaO2 = **98%**
- PaO2 = **300**

https://openart.ai/discovery/sd-1006969385782624387



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# Who would you rather be?

- Hgb = **15**
- SaO2 = **92%**
- PaO2 = **150**

https://www.wwe.com/gallery/andre-the-giant-larger-than-life-photos#fid-40198865



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# We have a winner!

- (12 x 1.34 x .95) + (300 x 0.003)
  - (15.27) + (0.9) = 16.17 ml O2/dl
- (15 x 1.34 x .92) + (150 x 0.003)
  - (18.49) + (0.45) = 18.94 ml O2/dl

https://aminoapps.com/c/officialwwe/page/blog/my-dream-matches-in-wwe/ZkVd_q3SBu8kaEeJB0eKvPw6EVmzKeLKN



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# Oxygen Content Take Away

- ***98% of total oxygen delivered to the tissues is bound to hemoglobin.***



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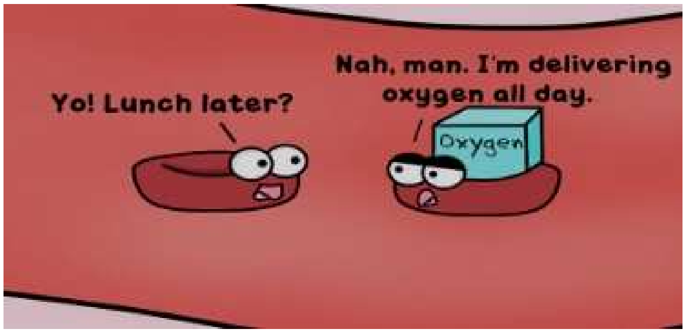
# Oxygen Delivery (DO2)

DO2 = CO x CaO2




https://x.com/AmoebaSisters/status/724363382447439873



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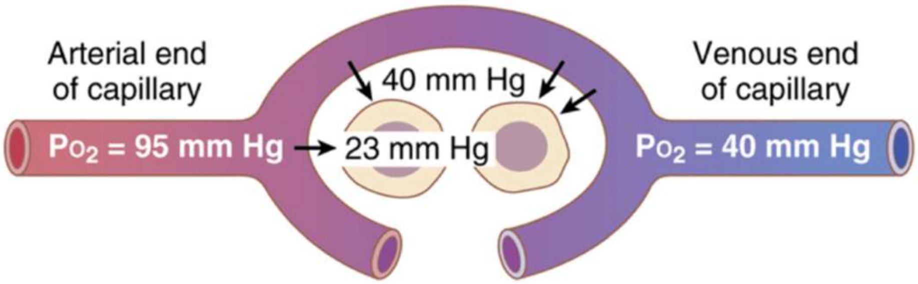
# Oxygen Consumption (VO2)

VO2 = CO x (CaO2– CVO2)




https://www.researchgate.net/figure/Diffusion-of-an-oxygen-molecule-from-the-arterial-end-of-a-capillary-to-tissue-cells-PO_fig3_347619719



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# Oxygen Consumption

- ***Increased***
  - Exercise
  - Trauma (including surgery and burns)
  - Pain
  - Sepsis/inflammation/fever
- ***Decreased***
  - Analgesia
  - Sedation
  - Paralysis
  - Hypovolemia
  - Hypothermia

ECMO Advantage



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# Oxygen Delivery vs Oxygen Consumption

- Oxygen delivery (DO2) adjusts to changes in oxygen consumption (VO2) maintaining a ratio of 5:1
- If VO2 increases relative to DO2 (or if DO2 is impaired), the body will compensate
- ***When the ratio is below 2:1 metabolism then switches from aerobic to anaerobic causing lactic acidosis.***

ECMO Advantage



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# Oxygen delivery/Consumption

## *5:1 = Good*

- $DO_2$ = 600 cc $O_2$/min/$m^2$
- $VO_2$ = 120 cc $O_2$/min/$m^2$
- *20% extraction = SVO2 = 80%*

## *2:1 = Bad*

- $DO_2$ = 500 cc $O_2$/min/$m^2$
- $VO_2$ = 300 cc $O_2$/min/$m^2$
- *50% extraction = SVO2 = 50%*

ECMO Advantage



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# How does this apply to ECMO?

ELSO

- Hypoxemic respiratory failure
  - $PaO_2/FiO_2 < 80$ mm Hg
- Hypercapnic respiratory failure
  - pH < 7.25 pH with a $PaCO_2 \geq 60$ mm Hg

Tonna at al., Management of Adult Patients Supported with VV ECMO: Guideline from ELSO; 2021

ECMO Advantage



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# Oxygenation during ECLS

- Oxygen uptake in the membrane lung
- Blood flow through the circuit (ECMO pump flow)
- Oxygen uptake through the native lung
- Blood flow (Cardiac output) through the native heart



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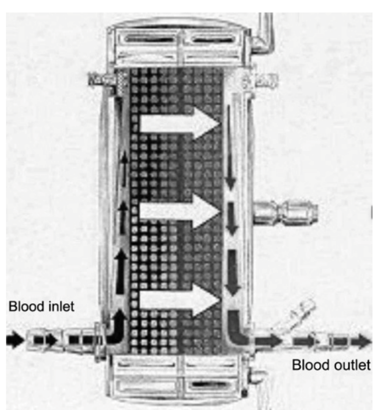
# Oxygenation in the Membrane Lung

*ECMO Blood (pump) flow 6 L/min*

*SVO2 60-75%*
*Hgb 10-12 gm/dl*




*SaO2 ≥ 95%*

Yeager & Roy, Evolution of Gas Permeable Membranes for ECMO; 2017



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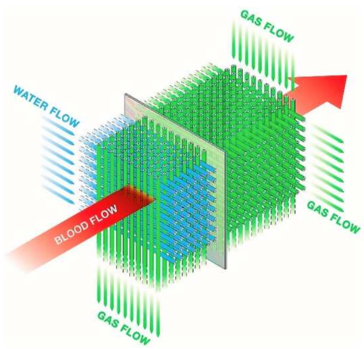
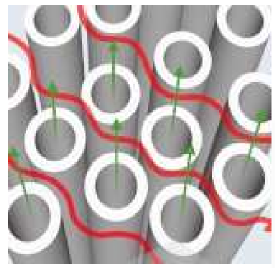
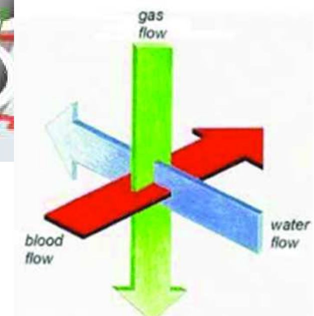
# Membrane Lung Function



Thi et al., Hemocompatability challenge of membrane oxygenator for artificial lung technology; 2022




Rajsic et al., Anticoagulation Strategies during ECMO: A Narrative Review; 2022



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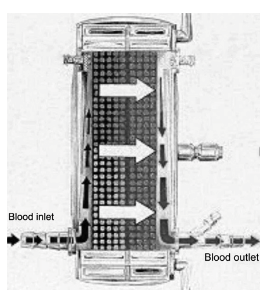
# Rated Flow

*ECMO Blood (pump) flow 6.5 L/min*

*SVO2 50%*
*Hgb 10 gm/dl*




*SaO2 ≥ ??*



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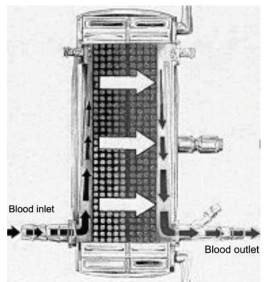
## Rated Flow

*ECMO Blood (pump) flow 7.5 L/min*

*SVO2 65%*
*Hgb 12 gm/dl*




*SaO2 ≥ ??*



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## Blood (pump) Flow through the Circuit

- The amount of the patient's cardiac output we are supporting with ECMO (pump flow) is directly associated with the amount of DO2 we are supporting.
- ***Ex: Ms. Swift has a total CO of 6 L/min. We are running her ECMO blood (pump) flow at 4.5 L/min.***
  - *4.5/6 = 75%*



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## Cardiac Output through Native Heart

- Changes in patient cardiac output (CO) through the native heart, with no change in ECMO blood (pump) flow, will result in varying degrees of oxygenation.
- Ex: Mr. Bon Jovi currently has a total CO of 6 L/min. We are running his ECMO blood (pump) flow at 4 L/min
  - 4/6 = 66% CO supported
  - 4/8 = 50% CO supported
  - 4/5 = 80% CO supported

ECMO Advantage



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## Oxygen Uptake Through Native Lungs

- If our ECMO patient has little to no oxygen uptake through the native lungs, then the membrane lung is supporting nearly all of the patient's gas exchange.
  - ***"Resting Vent Settings"***
    - Driving pressure < 15 cm H2O
    - Plateau pressure < 28 cm H2O
    - RR ~ 10
    - FIO2 decreased

ECMO Advantage



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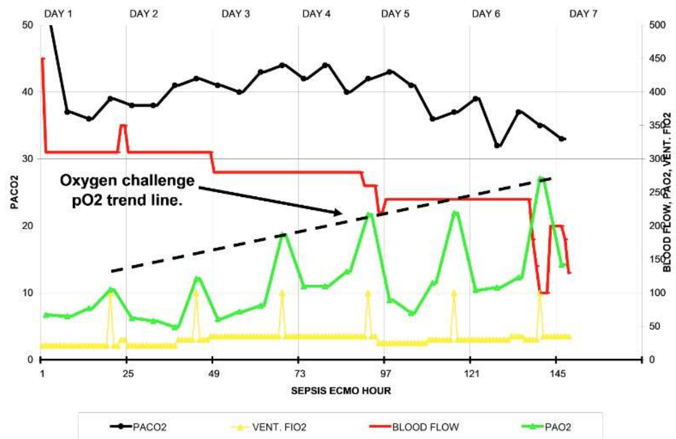
# Oxygen Uptake Through Native Lungs

- **Cilley Test** (Oxygen challenge)




https://perfusiontheory.com/the-oxygen-challenge-on-ecmo/



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# Ventilation During ECLS




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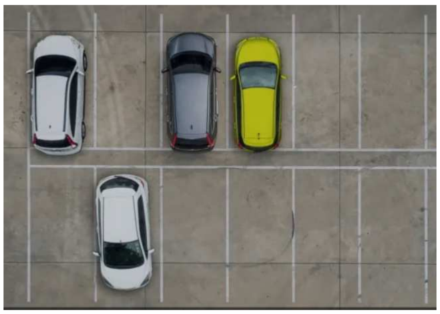
# Surface Area

Native Lung
100-150 $m^2$



https://www.mentalfloss.com/article/503014/why-america-has-so-many-empty-parking-spaces

ECMO Lung (Oxygenator)
1.8$m^2$



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# THANK YOU!



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## Consulting | Training | Staffing

Learn more about how ECMO Advantage works with hospitals and individual clinicians to help patients not just survive, but thrive!

WWW.ECMOADVANTAGE.COM



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