Pulmonary “Tests”

“What a Loyola MS 3 should know about Oxygenation, CO_2 elimination, and PFT’s”

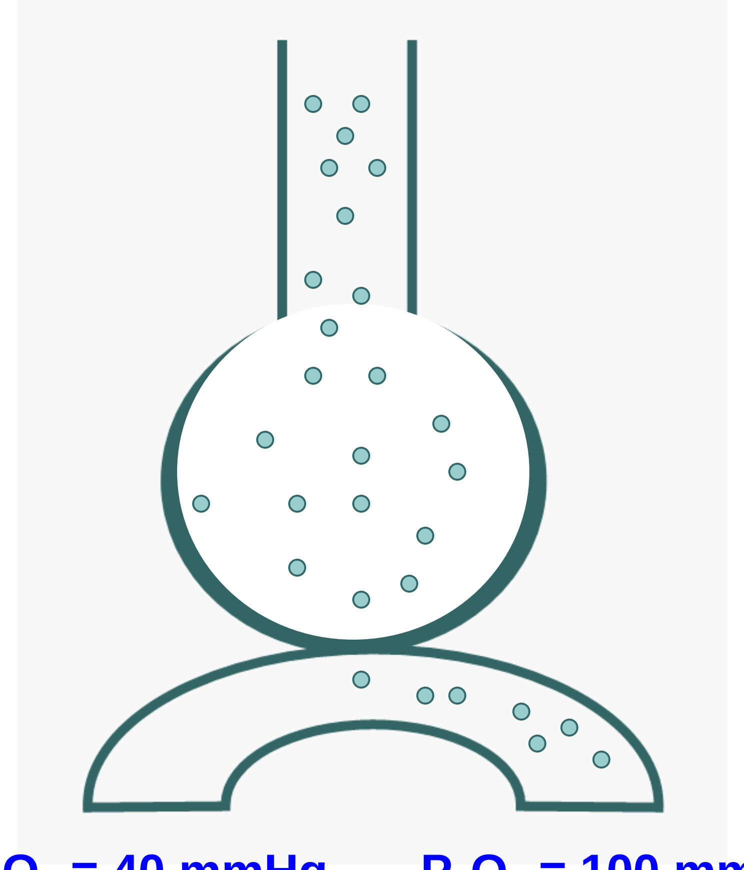
Learning Objectives

- Oxygenation:
  - Distinguish the various mechanisms of hypoxia
  - Know how to calculate the A-a Gradient
  - Understand oxygen content, delivery, and extraction
  - Recognize the various oxygen delivery devices
- CO_2 Elimination:
  - Know the principles determining one's CO_2
  - Understand the concept of Dead Space Ventilation
- PFT's:
  - Be able to interpret PFT's recognizing Obstruction, Restriction, and Diffusion Impairments

Approach to Hypoxemia

- Disease-Based
  - COPD/Asthma
  - Pulmonary Edema
  - ARDS
  - Pneumonia
  - ILD
  - Hypoventilation
  - Altitude
  - Decreased FIO2
  - Cirrhosis
  - Pulmonary Embolism
- Mechanism-Based
  - VQ Mismatch
  - Shunt
  - Diffusion Impairment
  - Hypoventilation
  - Decreased Barometric Pressure
  - Decreased F_IO_2
  - Diffusion-Perfusion Impairment
  - Mixed ?

Normal Physiology



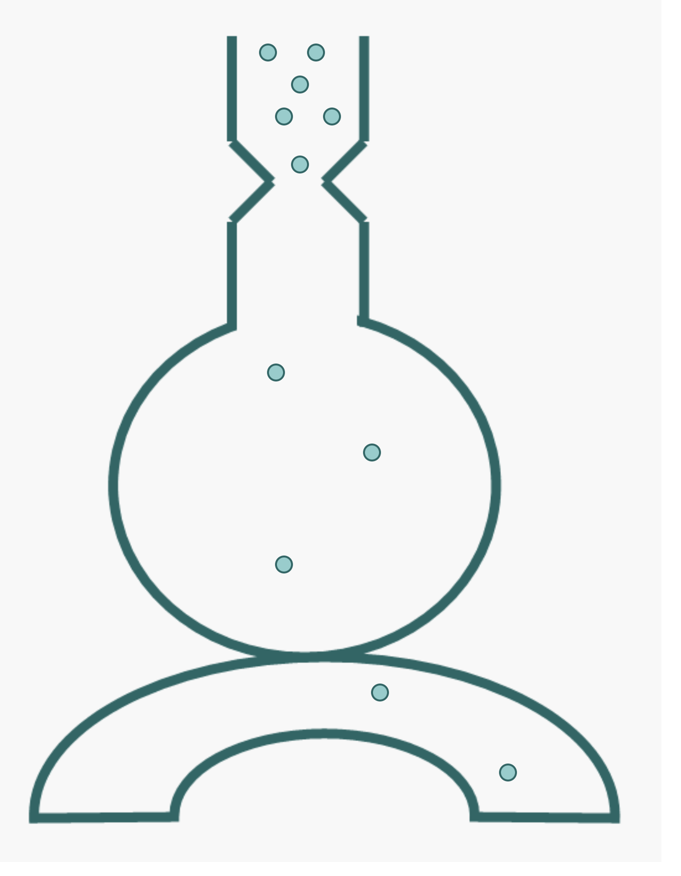
$P_{mv}O_2$ = 40 mmHg P_aO_2 = 100 mm Hg

Important Principles:

- Ventilation = Perfusion throughout
  - More of both at the bases
  - Less of both at the apices
- In health, no matter how low the $PmvO_2$ may be, PaO_2 will be normal

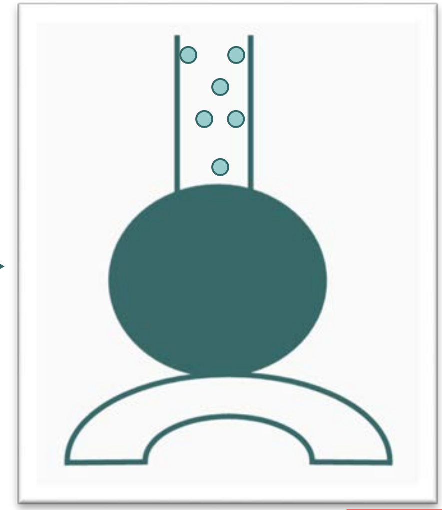
Mechanisms of Hypoxia: VQ Mismatch

- Decreased V relative to Q
- O_2 exits alveolus more quickly than enters via bronchi
- Hypoxia is MILD
- Hypoxia improves with supplemental O_2
- Causes:
  - Asthma, COPD
  - Pulmonary Emboli
  - ILD



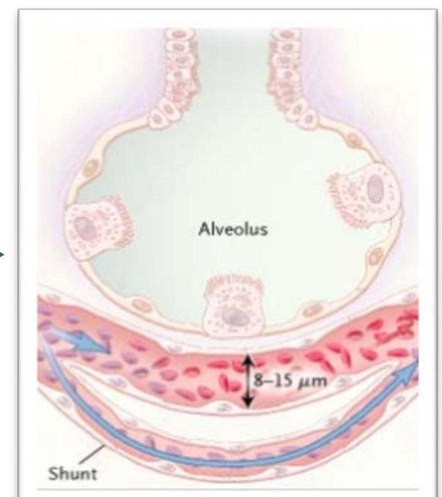
Mechanisms of Hypoxia: Shunt

- No O_2 reaches some set of pulmonary capillaries
- Hypoxia is SEVERE
- Hypoxia does NOT improve with supplemental O_2
- Causes:
  - Alveolar Disease:
    - NO ventilation to alveoli that are still perfused
      - Blood
      - Pus
      - Water
        - Pulmonary Edema
        - ARDS
      - Atelectasis
  - Anatomic Shunt
    - Pulmonary AVM
    - PFO, ASD, VSD

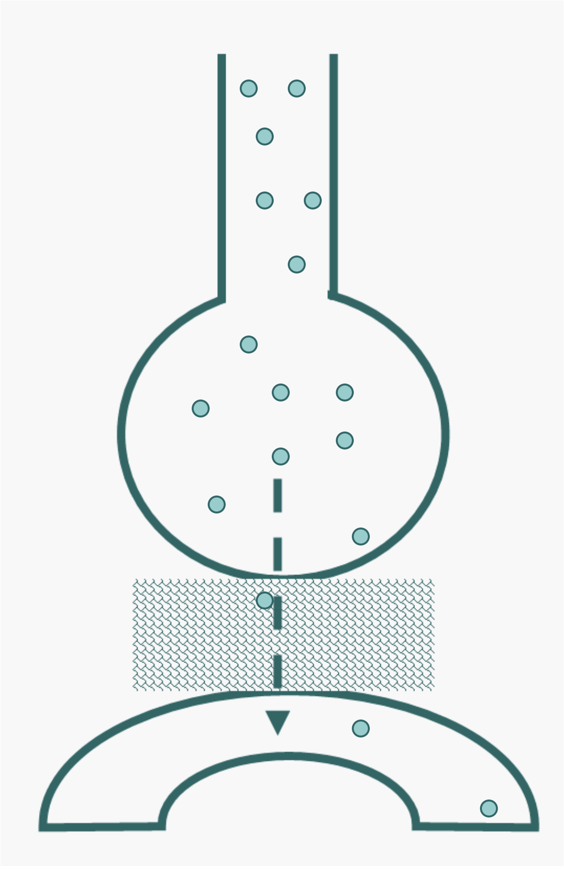


$P_{mv}O_2 = 40$

$P_aO_2 = 40$

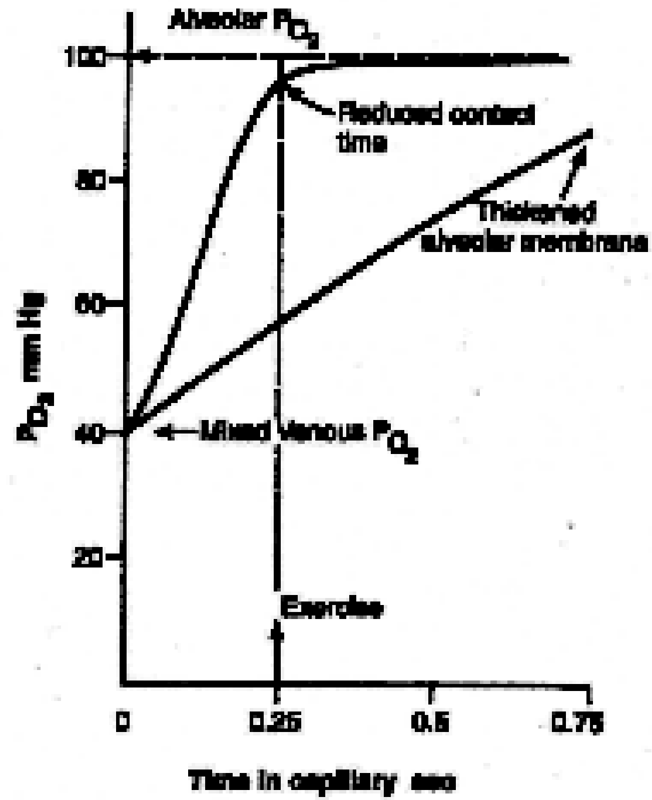


Mechanisms of Hypoxia:
Diffusion Impairment



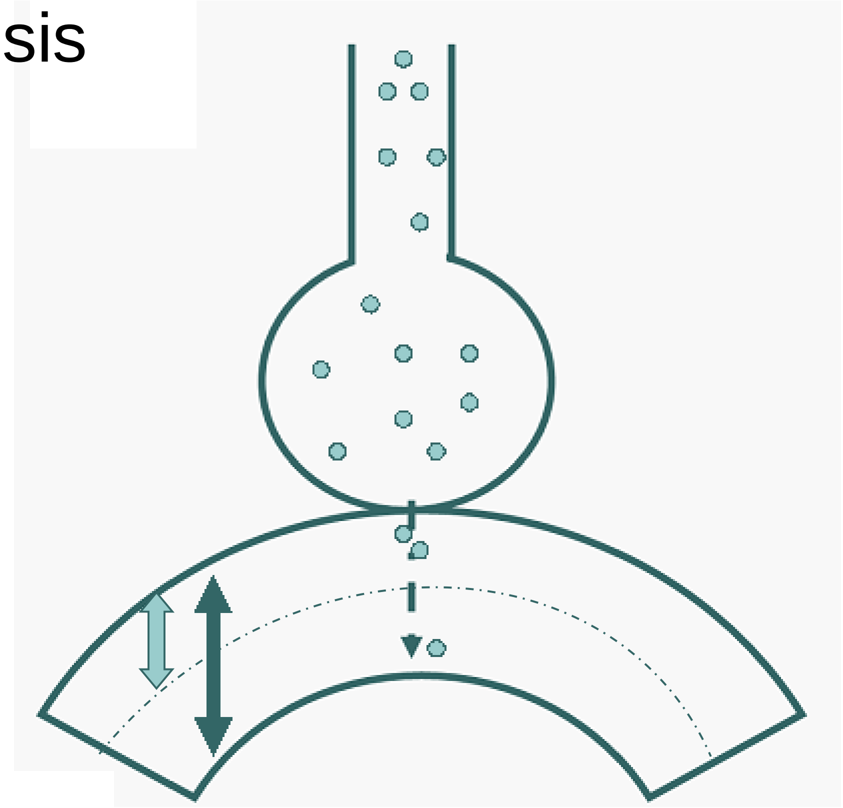
Mechanisms of Hypoxia: Diffusion Impairment

- NOT a common problem
  - Blood is normally fully oxygenated within 25% of its transit through the alveolar capillaries.
  - Therefore, even if slowed by a diffusion barrier, blood usually reaches full saturation
- Hypoxia is MILD
- Hypoxia improves with supplemental O_2



Mechanisms of Hypoxia:
Diffusion-Perfusion Impairment

- Seen occasionally in cirrhosis
- Dilated capillaries pose an impairment to full oxygenation



Mechanisms of Hypoxia

- VQ Mismatch
- Shunt
- Diffusion Impairment
- Diffusion-Perfusion Impairment
- Hypoventilation
- Altitude
- Decreased F_IO_2

The A-a Gradient

Two Questions

1. Which of these people has a lower than expected P_aO_2?

A. A MS3 in SSOM with a P_aO_2 = 95
B. 72 yo Doc Hering in SSOM with a P_aO_2 = 80
C. 50 yo Dr. Michelfelder in flight with a P_aO_2 = 50
D. A MS3 running at top speed with a P_aO_2 = 70

2. Which ABG illustrates abnormal O_2 Transfer from Alveolus to Capillary?

	$PaCO_2$	PaO_2
A.	40	95
B.	60	70
C.	20	95

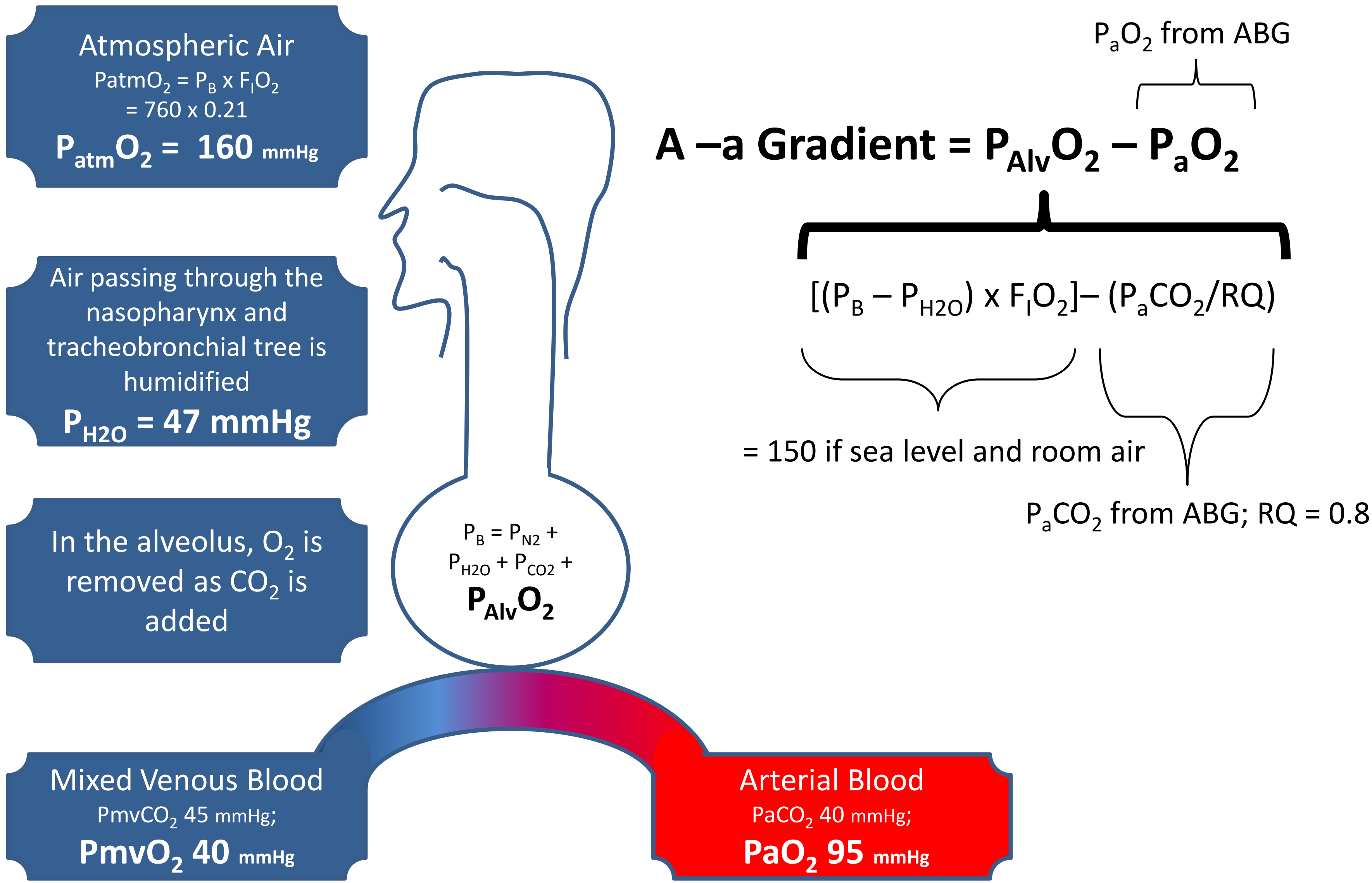
Write your answers down…

The A – a Gradient

calculated *measured*

- Mathematically = $P_{Alv}O_2 - P_aO_2$
  - Why is there any gradient?
    - Normal Anatomic and Physiologic Shunting
  - What is a normal gradient?
    - The A-a is normally less than age/4 + 4
  - What does an elevated A-a gradient imply?
    - A higher A-a gradient implies "disease" decreasing the efficiency of oxygen transfer from the atmosphere to the arterial circulation
- Answers the question "Is your patient's PaO_2 'normal'?"

What PaO_2 would you be happy with?



Atmospheric Air
$P_{atm}O_2 = P_B \times F_IO_2$
$= 760 \times 0.21$
$P_{atm}O_2$ = 160 mmHg
Air passing through the nasopharynx and tracheobronchial tree is humidified
P_{H2O} = 47 mmHg
In the alveolus, O_2 is removed as CO_2 is added
$P_B = P_{N2} + P_{H2O} + P_{CO2} +$
$P_{Alv}O_2$
Mixed Venous Blood
$P_{mv}CO_2$ 45 mmHg;
$P_{mv}O_2$ 40 mmHg
Arterial Blood
P_aCO_2 40 mmHg;
P_aO_2 95 mmHg
P_aO_2 from ABG
A –a Gradient = $P_{Alv}O_2 - P_aO_2$
$[(P_B - P_{H2O}) \times F_IO_2] - (P_aCO_2/RQ)$
= 150 if sea level and room air
P_aCO_2 from ABG; RQ = 0.8

Under "normal" circumstances….

… breathing room air at sea level

A "normal" Alveolar O_2 is:

$$P_{Alv}O_2 = [(P_B - P_{H2O}) \times F_IO_2] - (P_aCO_2/RQ)$$

$$[(760 - 47) \times .21] - (P_aCO_2/RQ)$$

$$150 - (40/0.8)$$

Therefore, $P_{Alv}O_2$ normally* = 150 - 50 = **100**

**But ….P_B, F_IO_2, P_aCO_2, and RQ can all be manipulated*

1. Which of these people has a lower than expected P_aO_2 ?

A. A MS3 in SSOM with a P_aO_2 = 95
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C. 50 yo Dr. Michelfelder in flight with a P_aO_2 = 50
D. A MS3 running at top speed with a P_aO_2 = 70

@ sea level, on room air, normal CO_2 and RQ means $P_{Alv}O_2$ should be @ 100 mm Hg

- A-a = 100-95 = 5… Normal
- A-a = 100-80 = 20
  - Age/4 + 4 = 22….. Normal
- At 8000 feet, P_B is only 565
  - (565-47) * 0.21 – (40/0.8) = 59
  - 59-50 = 9 Normal
- To repeat, normal people don't desaturate… ABNORMAL

2. Which ABG illustrates abnormal O_2 Transfer from Alveolus to Capillary?

	$PaCO_2$	PaO_2
A.	40	95
B.	60	70
C.	20	95

@ sea level, on room air, with a normal RQ,
$P_{Alv}O_2 = 150 – PaCO_2/0.8$

	$P_{alv}O_2$	A-a	Barrier?
A.	100	5	NO
B.	75	5	NO
C.	125	30	YES

Patient A is simply what we expect

Patient B is simply hypo-ventilating

Patient C is has SIGNIFICANTLY abnormal oxygen transfer despite an overtly normal PaO_2!!!

Clinical Question

- Treatment for *pneumocystis jiroveci* pneumonia in a patient whose ABG is 7.48/30/70 on room air?

How to describe the “degree” of hypoxia

- The “P/F” Ratio
  - P_aO_2/F_IO_2
  - Normally…
    - $P_aO_2/F_IO_2 \cong 100/0.2 = 500$
  - Lower P/F Ratios imply worsening degrees of hypoxia
    - P/F < 300 is bad enough hypoxia to count as ARDS

Other Oxygen Issues:

- How many mL of O_2 are in each dL of:
  - arterial blood?
  - venous blood?
- How much many mL of O_2 are delivered per minute to the tissues?
- What percent of the delivered O_2 is extracted by the tissues at rest?
- How are these numbers useful clinically?

Oxygen Content

- Conceptually:
  - Oxygen is carried in the blood as both:
    - Hemoglobin-Bound Oxygen
    - Dissolved Oxygen

Oxygen Content

Mathematically:

- $C_xO_2 = (Hgb)(S_xO_2)(1.34) + (P_xO_2)(0.003)$
- $C_aO_2 = (15)(1)(1.34) + (95)(0.003)$
  $\cong 20$ mL O_2/dL Blood
- $C_{mv}O_2 = (15)(\underline{0.75})(1.34) + (\underline{40})(0.003)$
  $\cong 15$ mL O_2/dL blood
- $D_{a\text{-}v}O_2 = C_aO_2 - C_{mv}O_2$
  $= 20 – 15 = 5$ mL O_2/dL blood

  i.e., the difference in O_2 content between arterial and venous blood

Oxygen Delivery

- Conceptually:
  - The amount of oxygen delivered to the tissues is the product of cardiac output and oxygen content.
- Mathematically:
  - D_aO_2 = C.O. x C_aO_2

    = 5 Lpm x 20 mL O_2/dL (x 10 dL/L)

    = 1000 mL O_2/min

Oxygen Extraction

- VO_2 = Oxygen Consumption
  - Normal = 250 cc/min at rest
- Extraction Ratio
  - % of delivered oxygen actually consumed
  - At rest:
    - 250 cc/min consumed
    - 1000 cc/min delivered
    - ER = 25%
      - Can increase to 75%

Oxygen Content, Delivery, Extraction: Summary

- Evidence of Inadequate Delivery relative to Consumption:
  - ⇩ $C_{mv}O_2$
  - ⇧ $D_{a-v}O_2$
  - ⇧ ER

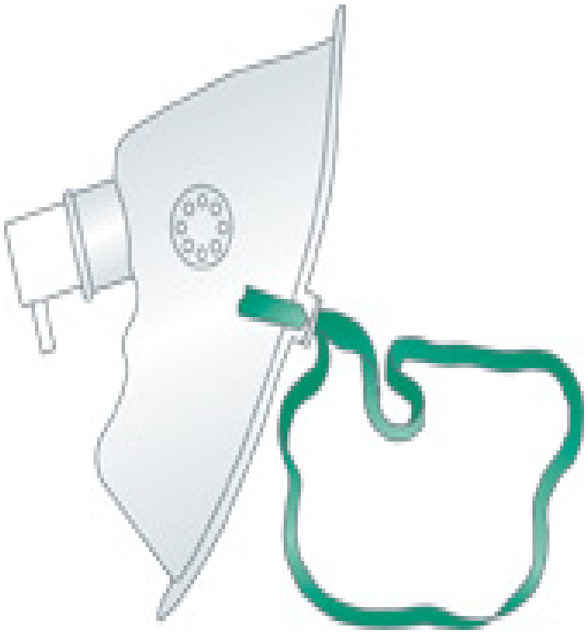
Oxygen Delivery Devices

- Nasal Cannula
  - 24-44% F_IO_2

  F_IO_2 increases ~ 3% for each additional liter per minute

Oxygen Delivery Devices

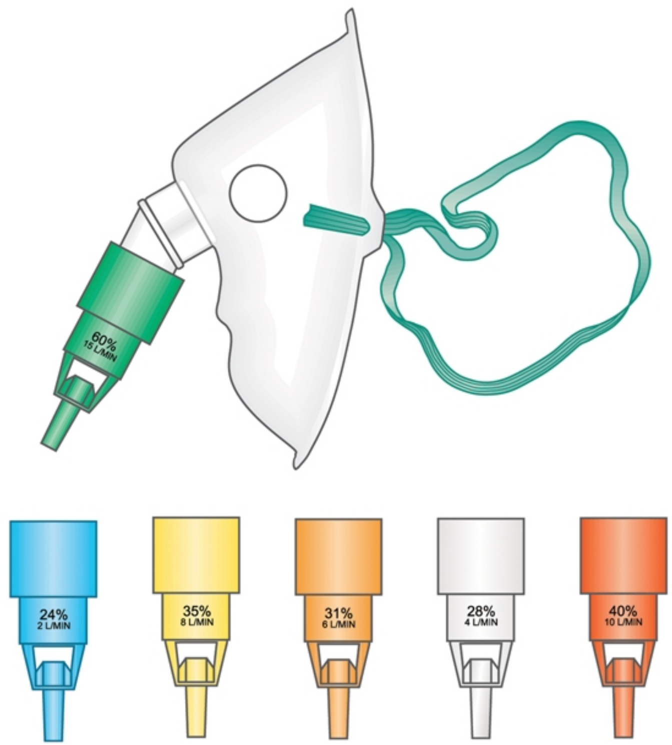
- Nasal Cannula
  - 24-44% F_IO_2
- Simple Face Mask
  - 40-60% F_IO_2



Oxygen Delivery Devices

- Nasal Cannula
  - 24-44% F_IO_2
- Simple Face Mask
  - 40-60% F_IO_2
- Non-Rebreather Mask
  - “reservoir” with one-way valve
  - 60-100% F_IO_2

Oxygen Delivery Devices



Interchangeable Venturi Valves

- Venturi Mask
  - Includes a valve allowing “precise” F_IO_2 delivery
    - ? Advantage for COPD patients
  - 24-60% F_IO_2

Oxygen Delivery Devices

- Optiflow®

  "Nasal High Flow Oxygen"

  - Heated and Humidified
  - "Flushes" out dead space
  - Provides a tiny amount of CPAP
  - Up to 100% F_IO_2

Oxygen Delivery Devices

- Nasal Cannula
  - 24-44% F_IO_2
- Simple Face Mask
  - 40 –60% F_IO_2
- Non-Rebreather Mask
  - 60-100% F_IO_2
- Venturi Mask
  - 24-60% F_IO_2
- Nasal HF O2
  - Up to 100% F_IO_2

What about P_aCO_2?

Conceptually:

- P_aCO_2 depends upon how much CO_2 is produced vs how much is eliminated.
- CO_2 elimination depends upon Alveolar Ventilation.
  - i.e., Total Ventilation minus Wasted Ventilation

Hence, the determinants of P_aCO_2 are:

- CO_2 Production
- Total Minute Ventilation
- Wasted Ventilation (i.e., “dead space” or V_D/V_T)

P_aCO_2

Mathematically…

- $P_aCO_2 \propto VCO_2 / [MV \times (1 - V_D/V_T)]$
  - $VCO_2 = CO_2$ Production
    - Normal = 200 ml/min
    - Increases in VCO_2 are <u>not</u> a clinically relevant cause of hypercapnea
  - MV = Minute Ventilation
    - Normal = 5 lpm at rest
    - Up to 100 lpm at maximum aerobic activity
    - Obviously, hypoventilation leads to hypercapnea
  - Therefore, if there is no increased VCO2 or decreased MV, hypercapnea must be due to increased V_D/V_T

Dead Space?

$P_aCO_2 \propto VCO_2 / [MV \times (1 - V_D/V_T)]$

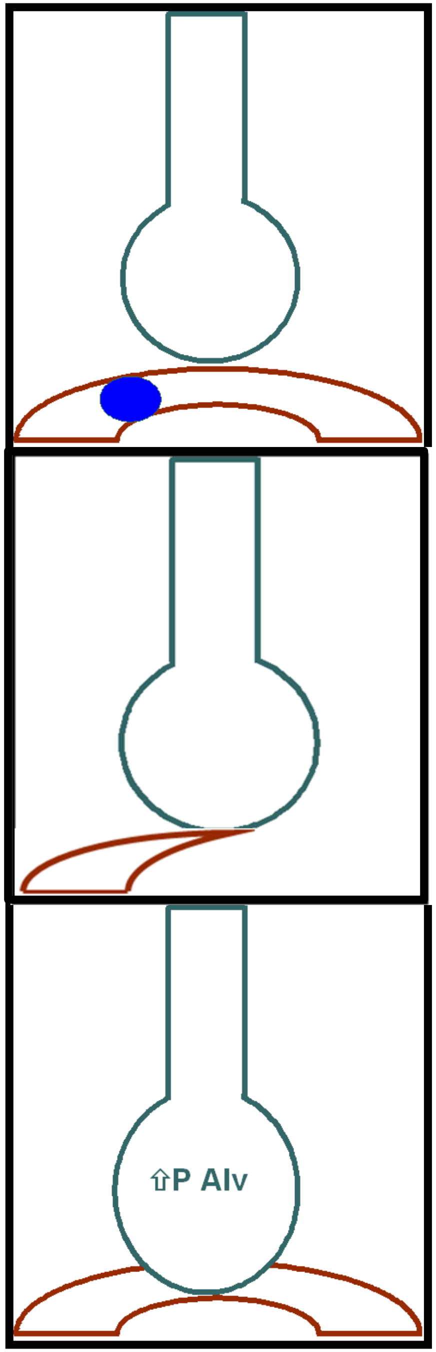
- V_D/V_T = "Dead Space" Ventilation
  - i.e., the percent of each tidal volume which does NOT participate in gas exchange
    - Includes 'anatomic' dead space
      - i.e., the air in the trachea and bronchi down to the conducting airways
    - AND includes physiologic dead space
      - i.e., air in alveoli that nonetheless is not participating in gas exchange
- Three Questions:
  - How much dead space is normal?
  - What are causes of increased dead space?
  - What is the consequence of increased dead space?

V_D/V_T

- Normally:
  - V_T ≅ 500 cc
  - V_D ≅ 1 cc/pound ≅ 150cc
  - V_D/V_T ≅ 150/500 ≅ 30% of an average TV

V_D/V_T

- Causes of increased V_D/V_T:
  - Decreased Perfusion of Ventilated Lung:
    - Pulmonary Emboli
    - Pulmonary Hypertension
    - Volume Depletion
  - Increased Alveolar Pressures:
    - PEEP (mechanical ventilation)
    - auto-PEEP (emphysema)



V_D/V_T Why does it matter?

- If increased V_D/V_T, one must increase minute ventilation which increases work of breathing.
- Think of increased V_D/V_T, whenever:
  - Increased P_aCO_2

    AND/OR
  - Normal P_aCO_2 with increased MV

PFT’s – practically speaking….

- Calculate expected values:
  - Age
  - Height
  - Sex
  - Race
- Measure patient values
- Compare
  - “normal” is defined by measured values that are between 80% and 120% of the predicted values

PFT's: 3 Main Components

Spirometry	Lung Volumes	Diffusing Capacity
↓FEV_1/FVC Obstruction	↓TLC Restriction	↓DLCO Pulmonary HTN
Asthma COPD Bronchiectasis	Interstitial Disease Chest Wall Disease Neuromuscular Disease	Associated with COPD and/or ILD Isolated = Primary Pulmonary HTN

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