Lecture 40
Gas Pressures and Lung Ventilation

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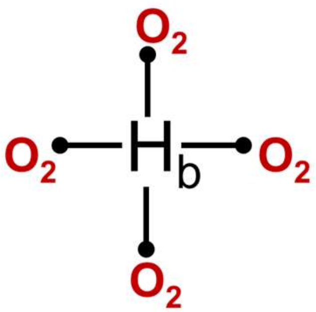
Gas Preliminaries

O_2 in Arterial Blood



@ 100% saturation how much Hb is in 100 ml of RBC's?

34 gHb/dl of RBCs

How much O_2 can 1 gHb carry? *≈ 1.34 mlO_2*

Theoretical O_2 binding capacity is about 1.39 ml O_2 / g of Hb ..... BUT
Some sites not available (~ due to small amounts of internally generated CO)
So … actual number is universally taken as ***1.34 ml O_2 bound / g of Hb***

@ a HCT of 0.44 what is the Hb concentration?

0.44 x 34 ≈ 15 gHb/dl BLOOD

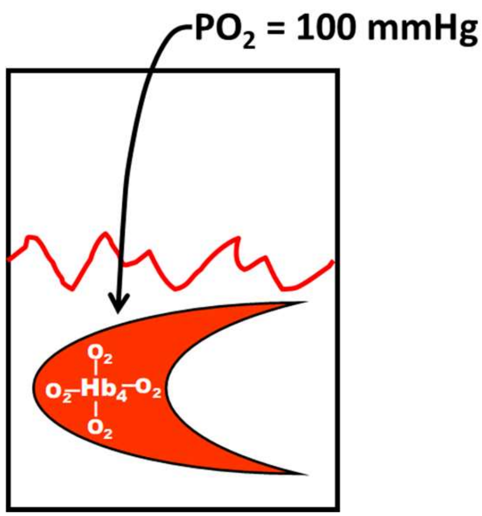
@ a 98% SAT what is BOUND [O_2]?

1.34 mlO_2/gHb x 15 gHb/dl x 0.98 = 19.7 mlO_2/dl

@ a PO2 of 100 mmHg what is the dissolved O_2/dl?

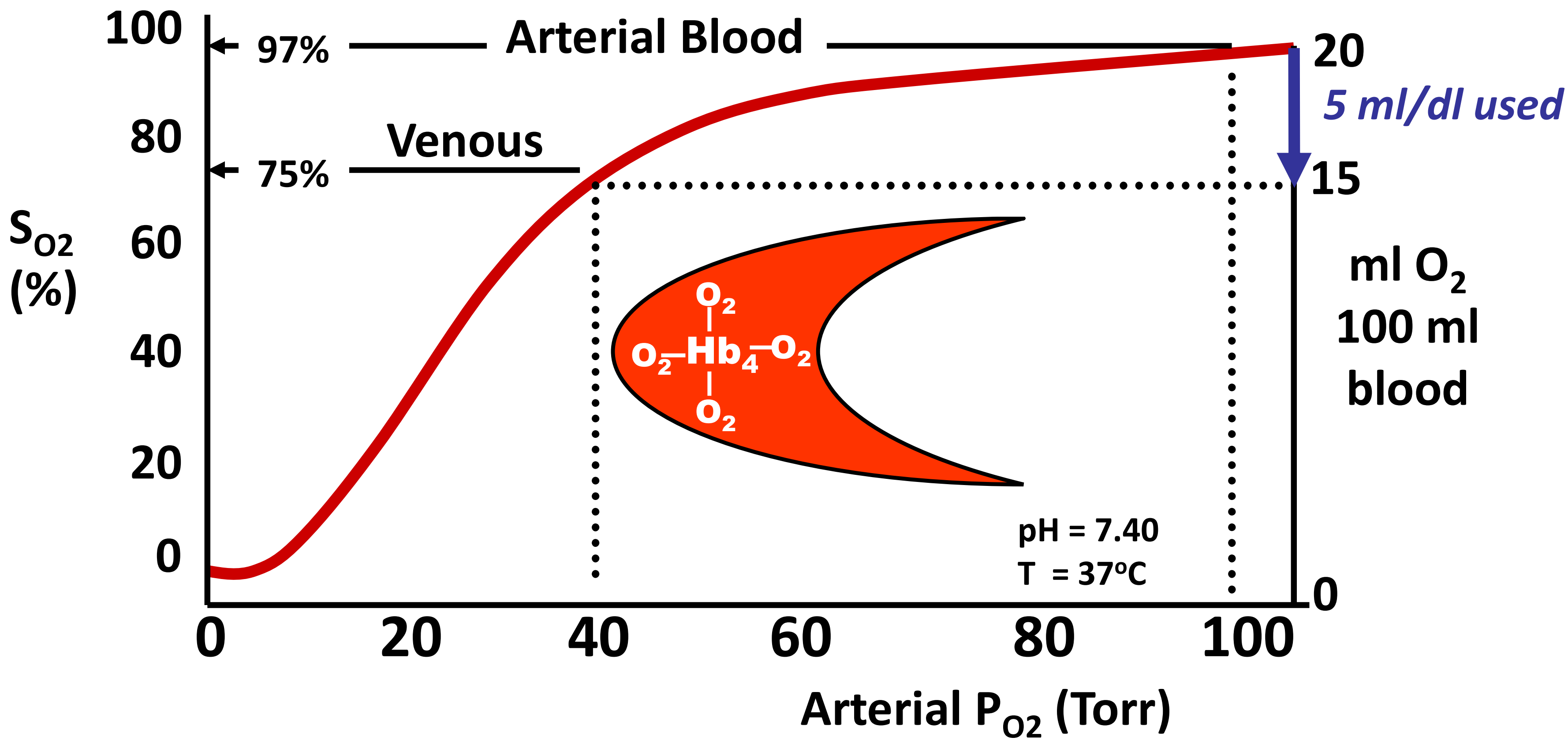
0.003 mlO_2/mmHg x 100 mmHg = 0.3 mlO_2/dl

Total carried in arterial blood ≈ 20 mlO_2/dl



Partial pressure differential drives gas diffusion

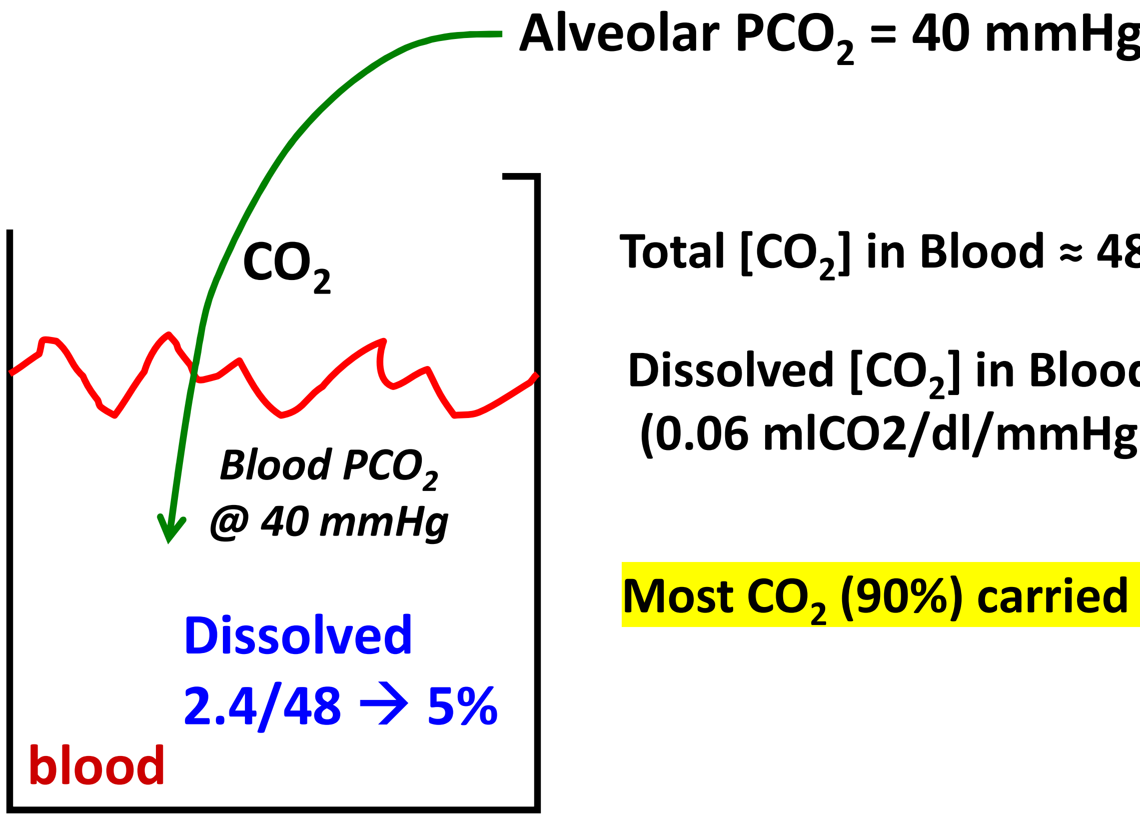
O_2 Association - and - Disassociation



mlO$_2$/100ml blood   g/100 ml bound   Amount Dissolved

$$[O_2] = 1.34\,[Hb]\,(Sat(\%)/100) + 0.003PO_2$$

Carbon Dioxide



Total $[CO_2]$ in Blood ≈ 48 ml/dl

Dissolved $[CO_2]$ in Blood = 2.4 $mlCO_2$/dl
(0.06 mlCO2/dl/mmHg) x 40 mmHg

Most CO_2 (90%) carried bicarbonate

Gas Pressures

Respiratory Gas Partial Pressures

	Dry Air
P_{O2}	159.6
P_{CO2}	0.0
P_{H2O}	0.0
P_{N2}	600.4
P_{total}	760

e.g. Dry Air = 0.21 x 760 Torr = 159.6 Torr

Respiratory Gas Partial Pressures

	Dry Air	Moist Tracheal Air
P_{O2}	159.6	149.7
P_{CO2}	0.0	*0*
P_{H2O}	0.0	47
P_{N2}	600.4	563.3
P_{total}	760	760

← Humidification @ 37° C

e.g. Dry Air = 0.21 x 760 Torr = 159.6 torr
e.g. Trachea = 0.21 x (760 - 47) = 149.7 torr

Respiratory Gas Partial Pressures

Rounded values

	Dry Air	Moist Tracheal Air
P_{O2}	160	150
P_{CO2}	0.0	*0*
P_{H2O}	0.0	47
P_{N2}	600	563
P_{total}	760	760

← Humidification @ 37° C

e.g. Dry Air = 0.21 x 760 Torr = 159.6 torr
e.g. Trachea = 0.21 x (760 - 47) = 149.7 torr

Respiratory Gas Partial Pressures

	Dry Air	Moist Tracheal Air	Alveolar Gas
P_{O2}	160	150 →	*102*
P_{CO2}	0.0	*0* →	*40*
P_{H2O}	0.0	47	*47*
P_{N2}	600	563	571
P_{total}	760	760	760

Respiratory Gas Partial Pressures

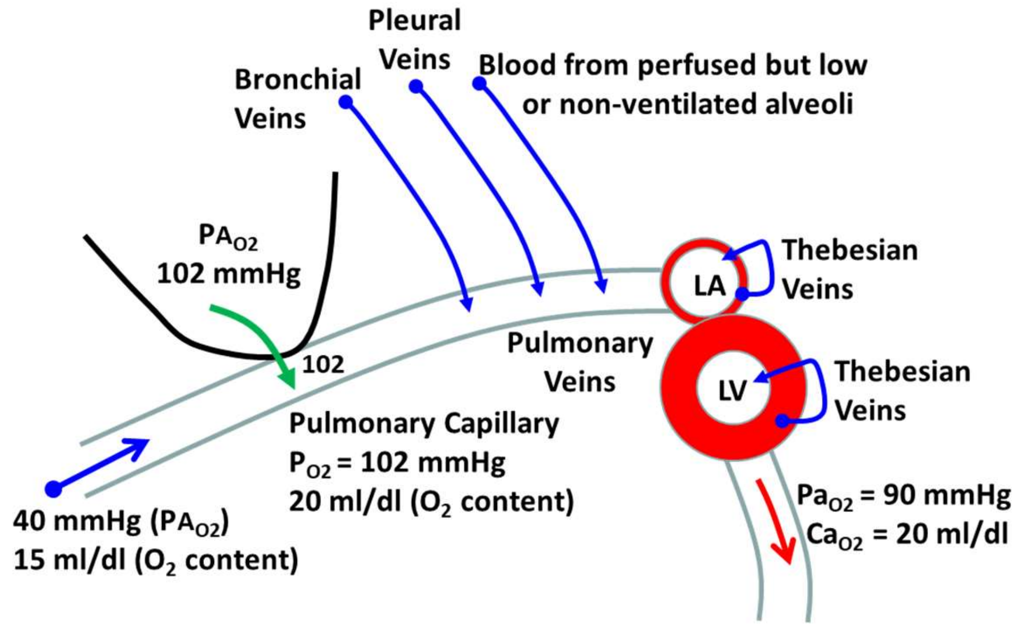
	Dry Air	Moist Tracheal Air	Alveolar Gas	Arterial Blood	
P_{O2}	160	150 →	*102* →	*90*	
P_{CO2}	0.0	*0* →	*40*	*40*	
P_{H2O}	0.0	47	*47*	47	
P_{N2}	600	563	571	571	
P_{total}	760	760	760	748	

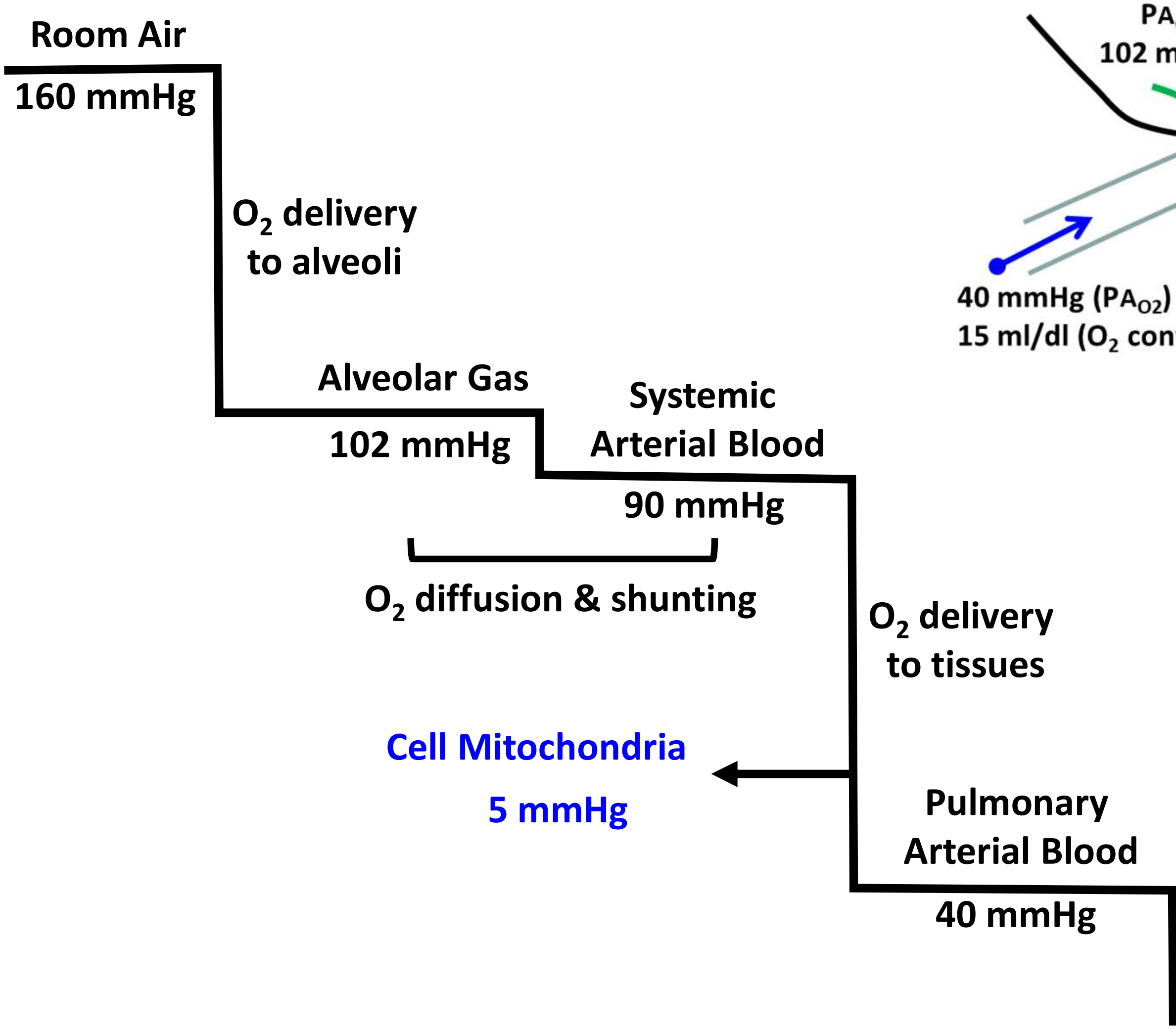
Respiratory Gas Partial Pressures

	Dry Air	Moist Tracheal Air	Alveolar Gas	Arterial Blood	Mixed Venous Blood
P_{O2}	160	150	*102*	*95* →	*40*
P_{CO2}	0.0	0.0	*40*	*40* →	*46*
P_{H2O}	0.0	47	*47*	*47*	*47*
P_{N2}	600	563	569	569	571
P_{total}	760	760	760	756	704

Mixed Venous Blood = Pulmonary Artery Blood
PO_2 and PCO_2 in dry air and trachea are "round-offs"

Oxygen Cascade

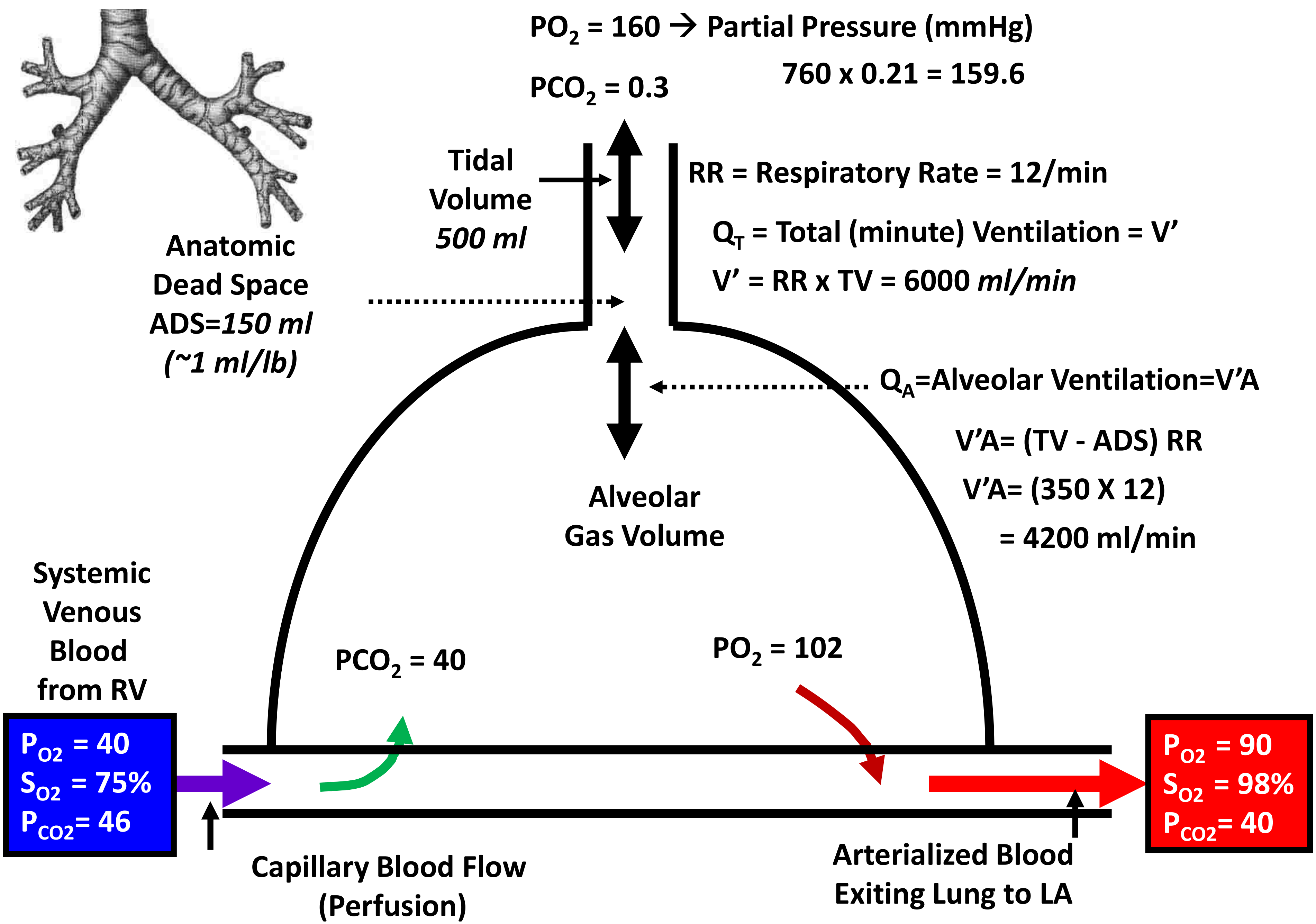




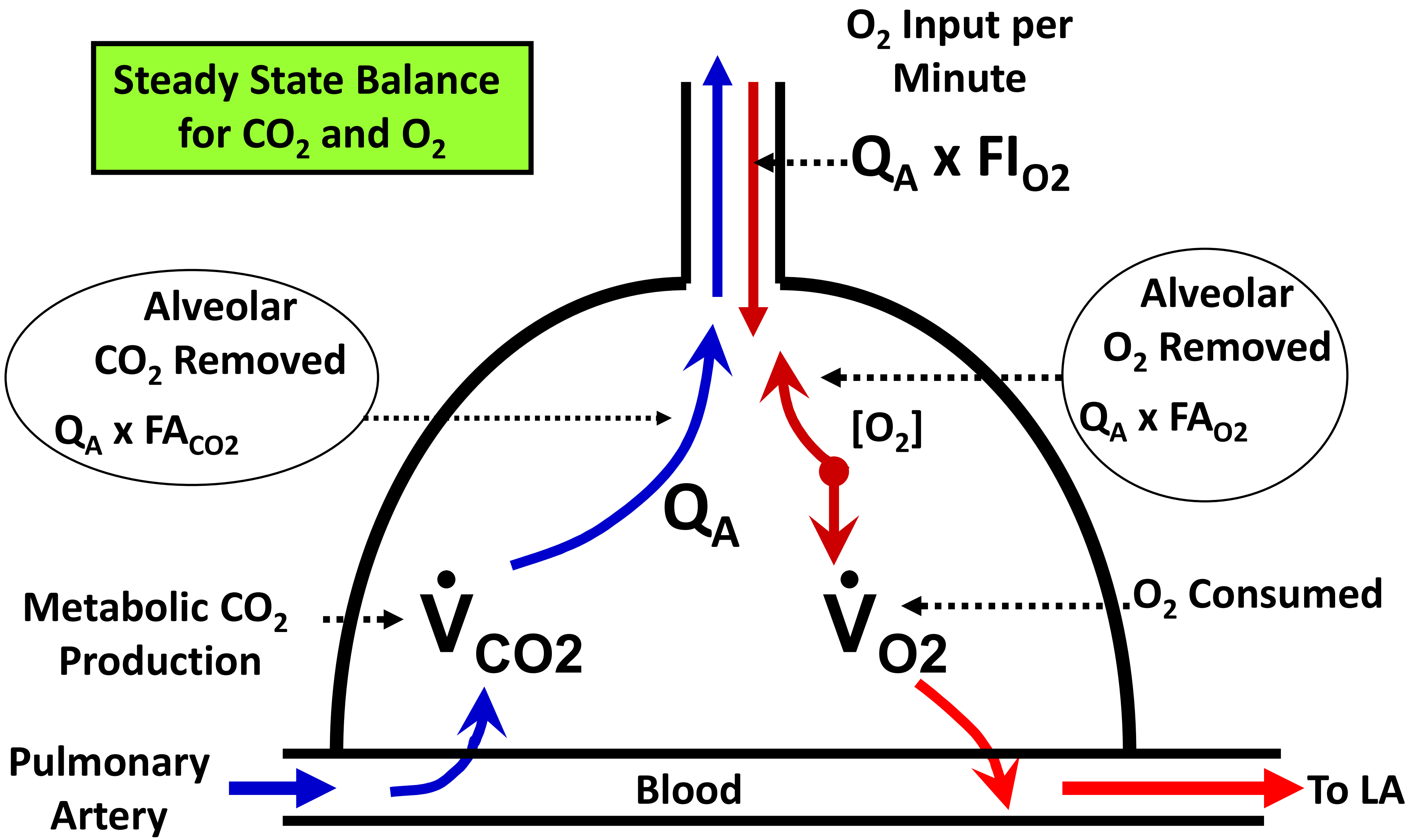
- For ideal gas exchange P_{O2} in alveoli and capillary would nearly equilibrate at ≈ 102 mmHg
- Blood entering at various points that has NOT been oxygenated serves to dilute the O_2 content and reduce the partial pressure
- This represents shunting due to both anatomical and other processes.

Ventilation

Ventilation Related Processes: REVIEW



Alveolar Gas Movements

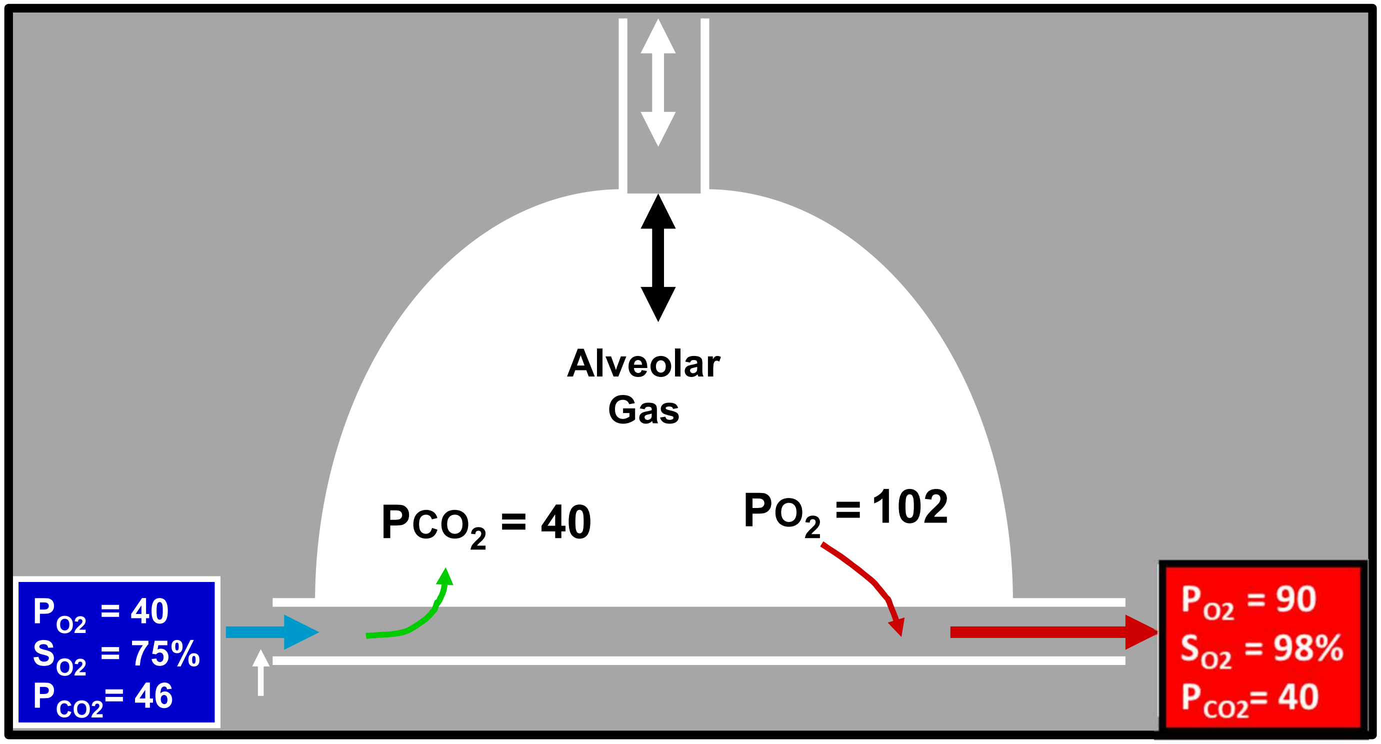


CO_2 Tension: Alveolar vs. Arterial

- Normally Arterial PCO_2 is very close to Alveolar PCO_2

- $Pa_{CO2} \approx PA_{CO2}$
  Arterial Alveolar

- So when we talk about alveolar CO_2 tension it almost always applies to arterial



Alveolar Ventilation Equation: Basic Concept

$$PA_{CO2} = K \frac{CO_2 \text{ Production}}{\text{Alveolar Ventilation}} = K \frac{\dot{V}_{CO_2}}{Q_A}$$

K = 0.863 (mmHg) with $V'CO_2$ in ml/min and Q_A in L/minute

K = 863 (mmHg) with $V'CO_2$ in ml/min and Q_A in ml/minute

- **Hypoventilation** if ratio too high: PA_{CO2} rises
- **Hyperventilation** if ratio is too low: PA_{CO2} falls

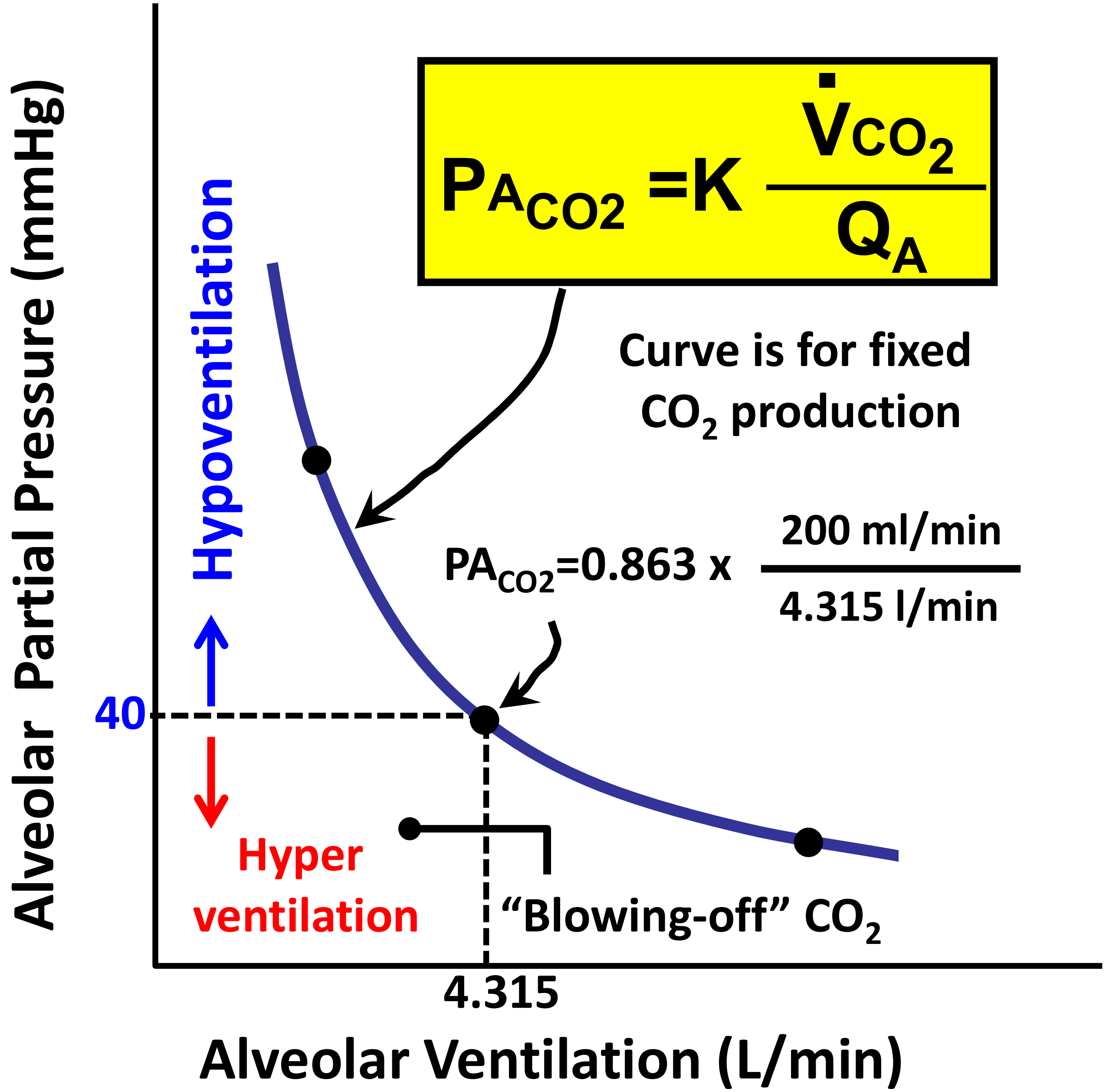
If as usual, P_{ATM} = 760 mmHg and Q_A measured at 310°K (37°C) and V'_{CO2} measured at 273° STP

Then K = 760 mmHg x (310K/273K) = 760 x 1.1355 = 863 as shown above

Berne and Levy equation 23.16 not quite correct!

Alveolar Ventilation Equation

- Normally Arterial PCO_2 very close to Alveolar PCO_2
- Pa_{CO2} ~ PA_{CO2}
  Arterial Alveolar
- So, when we talk about alveolar CO_2 tension it almost always applies to arterial



Example Application

A student at NSU MD voluntarily alters her breathing pattern by doubling her breathing rate and decreasing her tidal volume from 500 to 250 ml. She weighs 100 pounds, and her anatomical dead space is estimated as 1 ml/lb.

What is the effect on her voluntary maneuver or alveolar CO_2 tension?

PA_{CO2} =K (CO_2 production/Alveolar Ventilation)

Alveolar ventilation = Q_A = (TV - ADS)RR

Alveolar Ventilation Calculation

Normal: (500 -100)RR   Voluntary: (250 -100)2RR

Q_A: 400RR < 300RR

In this example PA_{CO2} Increases

Hypoventilation or Hyperventilation???

Alveolar Gas Equation

Basic Concept

PA_{O2} depends on:

- **Composition of inspired air (F_{IO2})**
- **Atmospheric pressure (P_{ATM})**
- **Respiratory Quotient ($R = CO_2/O_2$)**
- **PA_{CO2}**

Complete Alveolar Gas Equation

$$PA_{O2} = \underbrace{(P_{ATM} - 47) \times F_{IO2}}_{PO_2 \text{ (trachea)}} - \underbrace{PA_{CO2}}_{\text{Alveolar } CO_2} \underbrace{[F_{IO2} + (1-F_{IO2})/R]}_{\text{"Correction" factor}}$$

R = respiratory exchange ratio
= CO_2 produced/O_2 consumed

Calculation at sea level with room air

$$PA_{O2} = (760-47) \times .21 \quad - 40 \quad [.21 + (1-.21)/.8]$$

$$PA_{O2} = \quad (713) \quad \times .21 \quad - 40\ [1.2]$$

$$PA_{O2} \approx \quad 150 \quad - 40\ [1.2] \quad = 102 \text{ torr}$$

$PA_{O2} \approx 150 - 1.2\ PA_{CO2}$ ***for room air at sea level***

Approximate Equation B&L 23.13

$$PA_{O2} = \underbrace{(P_{ATM} - 47) \times F_{IO2}}_{PO_2 \text{ (trachea)}} - PA_{CO2}/R$$

$$PA_{O2} \approx \quad 150 \quad - 40/0.8 \quad = 100 \text{ torr}$$

Interactive Questions

A student while at NSU MD, voluntarily alters her breathing pattern by doubling her breathing rate and decreasing her tidal volume from 500 to 250 ml. She weighs 100 pounds, which is within 20% of her normal weight range.

- **What is her approximate anatomical dead space?**
- **If her initial respiratory rate was 10 /minute what is alveolar ventilation?**
- **Assuming her alveolar CO_2 tension is in the normal range (42 mmHg) what is her alveolar O_2 tension?**

Uneven Alveolar Ventilation

Gravity Main Effects

- **Alveoli at base have less volume but greater compliance**

- **Result is a better ventilation of base alveoli during normal TV**

Uneven Ventilation: Gravity Effects

P_{ALV}

Does not depend on gravity

BUT

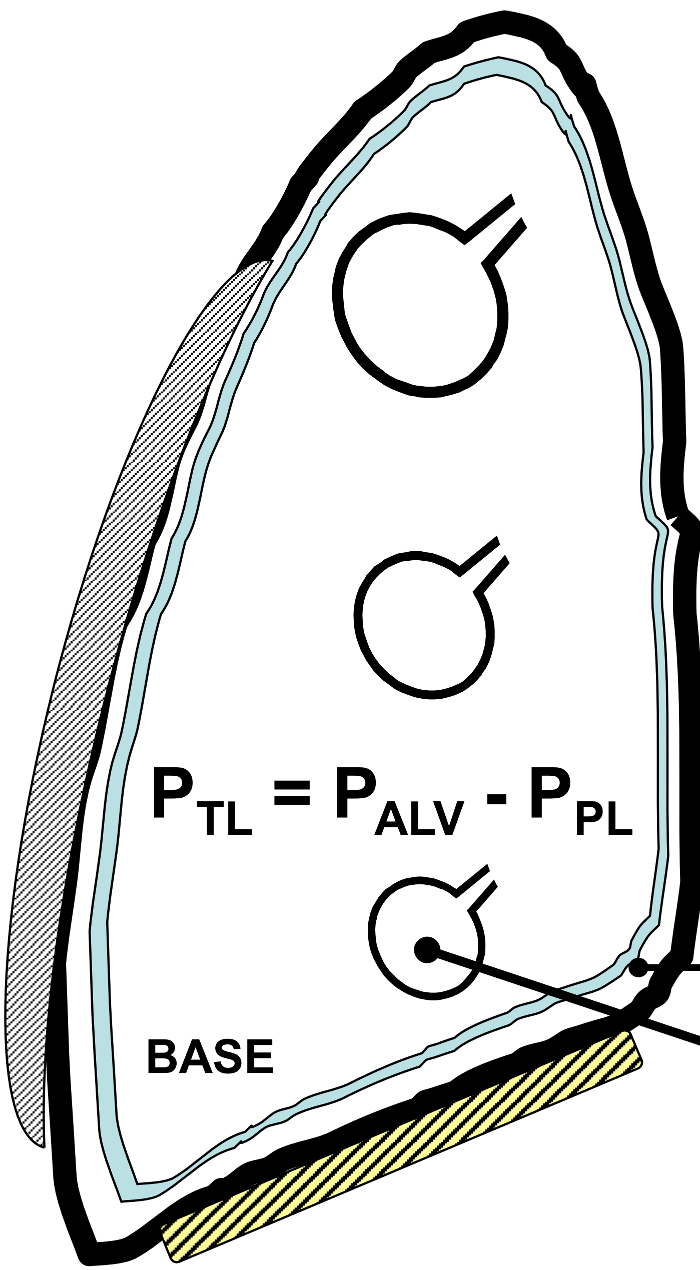
P_{PL}

does!

So ….

P_{TL}

varies with height



1. Lung tissue behaves as a low density fluid r= 0.28 g/cm^2
2. Intrapleural fluid height represents a "column"

Higher intrapleural pressure (P_{PL})

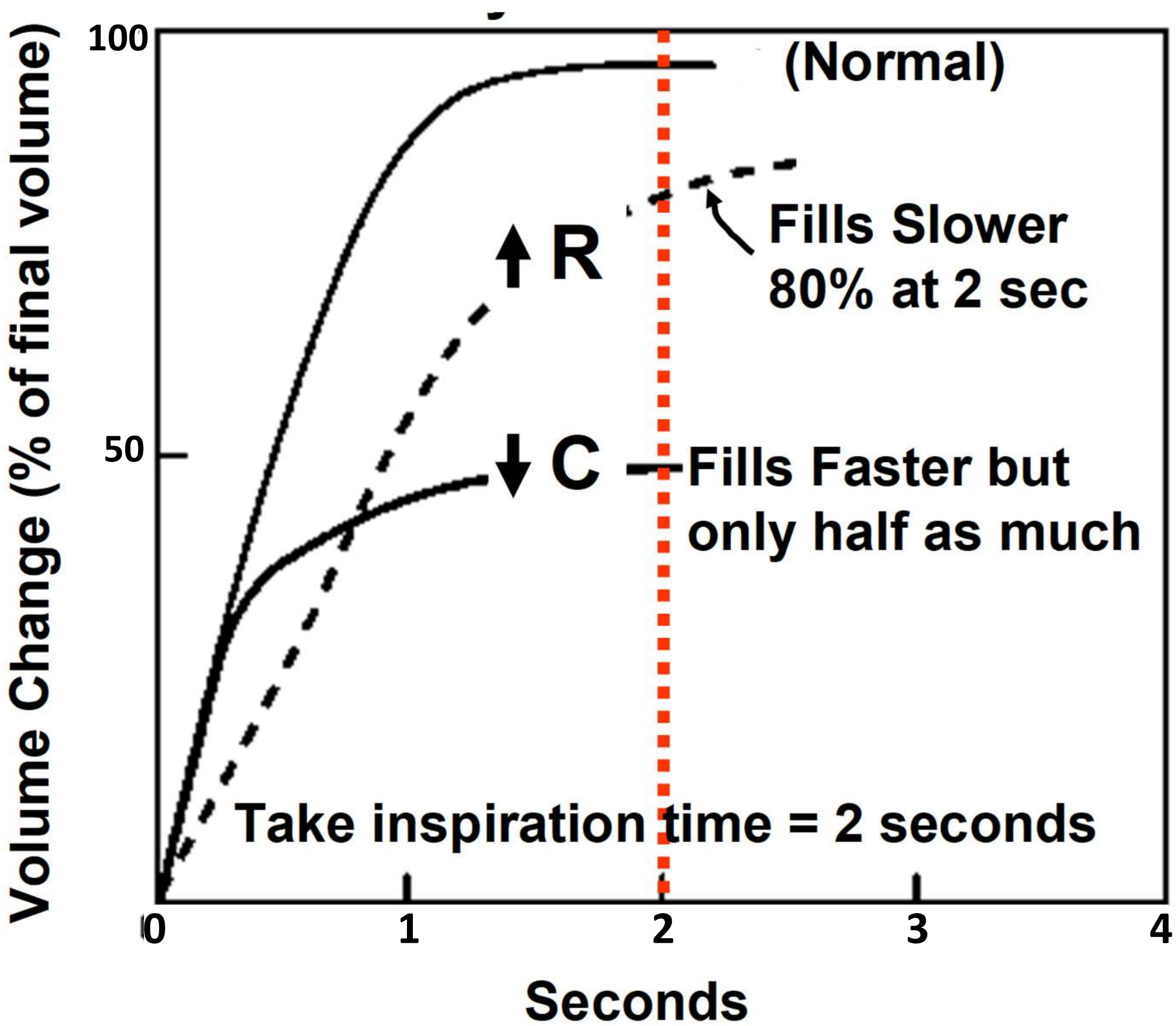
- Less Transmural Pressure
- Less Alveolar Volume
- Less P_{REC} → Greater C

Uneven Ventilation : Variable Time Constants

Time Constant Effects

- Time Constant = R x C = τ
- Time to fill/empty ~ τ
- Variability in τ causes uneven alveolar ventilation within lung

Effects of Uneven Time Constants



- Variations in τ through out the lung are a source of uneven ventilation
- Amount of ventilation of a specific alveolus during a breathing cycle depends on the relative amount of gas exchange within that alveolus
- Rate of filling and emptying depends on τ that in turn depends on resistance of small airways connected to the alveoli and alveoli compliance
- A greater RC product indicates slower gas exchange within the alveoli

Interactive Review Questions

1. What is the approximate oxygen percentage in air on the Mt. Everest ___21%___?

2. Normal PCO_2 of blood entering pulmonary capillaries is about ___46 mmHg___ ?

3. Normal PO_2 of blood returning to the pulmonary circulation is about ___40 mmHg___?

4. The normal level of water vapor pressure in the lung is about ___47 mmHg___?

5. According to the Alveolar Ventilation Equation, if alveolar ventilation decreases in relation to CO_2 removal, what happens to alveolar CO_2 tension?

$$P_{A_{CO2}} = K \frac{\dot{V}_{CO_2}}{Q_A}$$

increases

6. According to the Alveolar Gas Equation, if alveolar PCO_2 increases, what happens to alveolar PO_2

$$PA_{O2} = (P_{ATM} - 47) \times F_{IO2} - PA_{CO2}\,[F_{IO2} + (1-F_{IO2})/ R]$$

decreases

$$PA_{O2} = (P_{ATM} - 47) \times F_{IO2} - PA_{CO2}/R$$

7. If Mary breathes 80% oxygen at a pressure of 2 atmospheres, what is her tracheal PO_2?

2 Atm = 2 x 760 mmHg = 1520 mmHg

PO_2 (trachea) = 0.8 x (1520 – 47) = 1178.4 mmHg

Interactive MCQs

Which pulmonary feature largely accounts for the normally high value of lung interstitial oncotic pressure?
A. Low pulmonary capillary hydrostatic pressure
B. High pulmonary capillary oncotic pressure
C. High value of pulmonary lymphatic flow
D. Low value of pulmonary capillary reflection coefficient
E. High value of total pulmonary blood flow

At FRC, which of the following is true?
A. Lung compliance is at, or near, its minimum value
B. Pulmonary vascular resistance is near its maximum value
C. Chest wall recoil is at its minimum value
D. Chest wall recoil is at its maximum value
E. Chest wall and lung recoil are equal and oppositely directed

Which one of the following statements is true regarding airway resistance?
A. It decreases as the lung expands because airways lengthen
B. It is largest in smaller airways because of their smaller diameter
C. Its value decreases with increasing lung volume
D. If increased, it will tend to cause airway collapse during inspiration
E. Its increase is the main finding in restrictive lung disease

End Respiratory Physiology
Lecture 40