MEDICINE
KING SAUD UNIVERSITY

Physiology Team 436

Revised by
شوق الأحمري & طراد الوكيل

Gas Transfer
(Diffusion of O2 and CO2)

RESPIRATORY BLOCK

Red: very important.
Green: Doctor's notes.
Pink: formulas.
Yellow: numbers.
Gray: notes and explanation.

Physiology Team 436 – Respiratory Block Lecture 6

Lecture: If work is intended for initial studying.
Review: If work is intended for revision.

Objectives

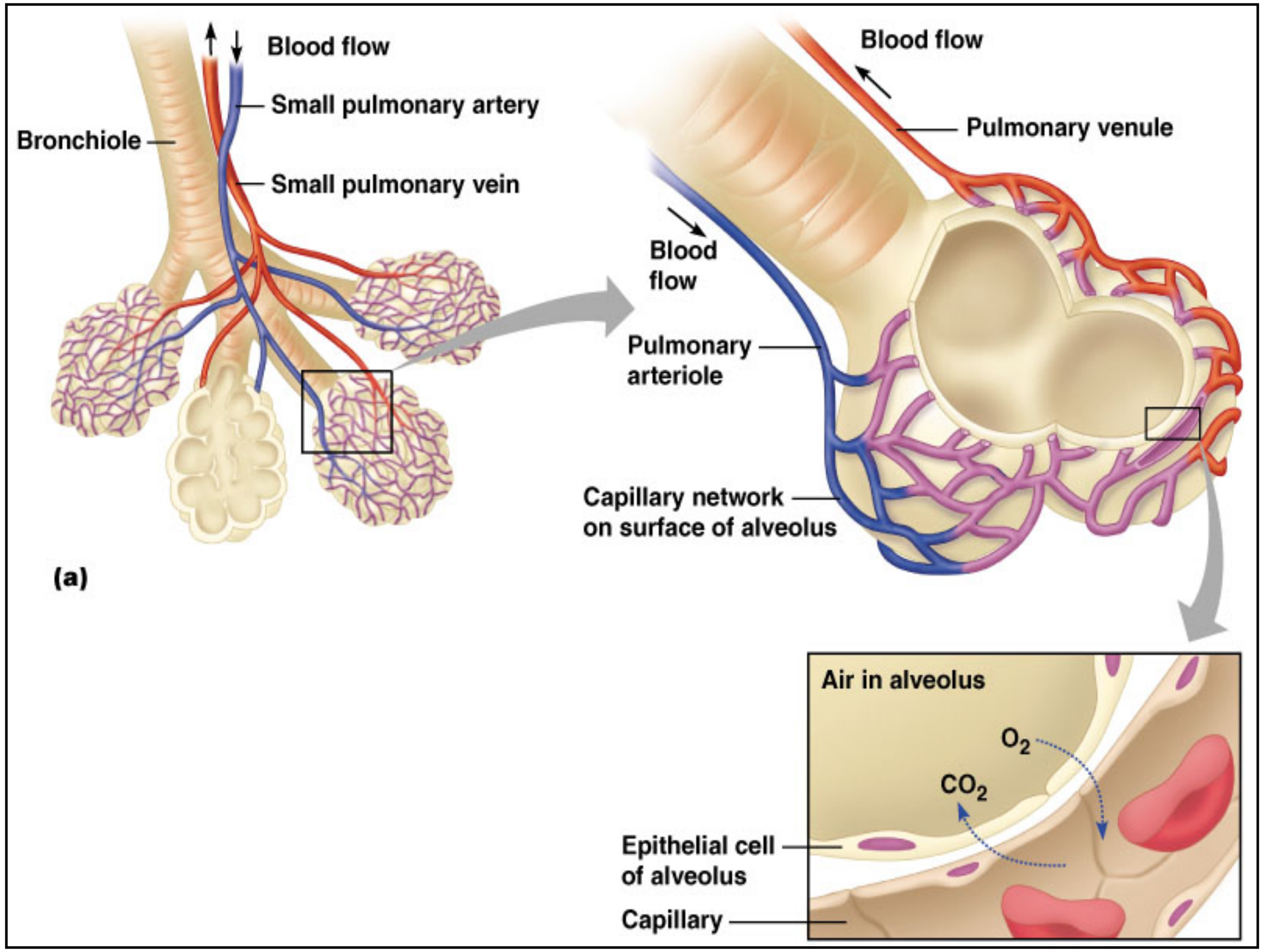
- Define partial pressure of a gas.
- Understand that the pressure exerted by each gas in a mixture of gases is dependent on the pressure exerted by the other gases (Dalton's Law)
- Understand that gases in a liquid diffuse from higher partial pressure to lower partial pressure (Henry's Law)
- Describe the factors that determine the concentration of a gas in a liquid.
- Describe the components of the alveolar-capillary membrane (i.e., what does a molecule of gas pass through).
- Knew the various factors determining gas transfer: - Surface area, thickness, partial pressure difference, and diffusion coefficient of gas
- State the partial pressures of oxygen and carbon dioxide in the atmosphere, alveolar gas, at the end of the pulmonary capillary, in systemic capillaries, and at the beginning of a pulmonary capillary.

Gas Exchange Through the Respiratory Membrane

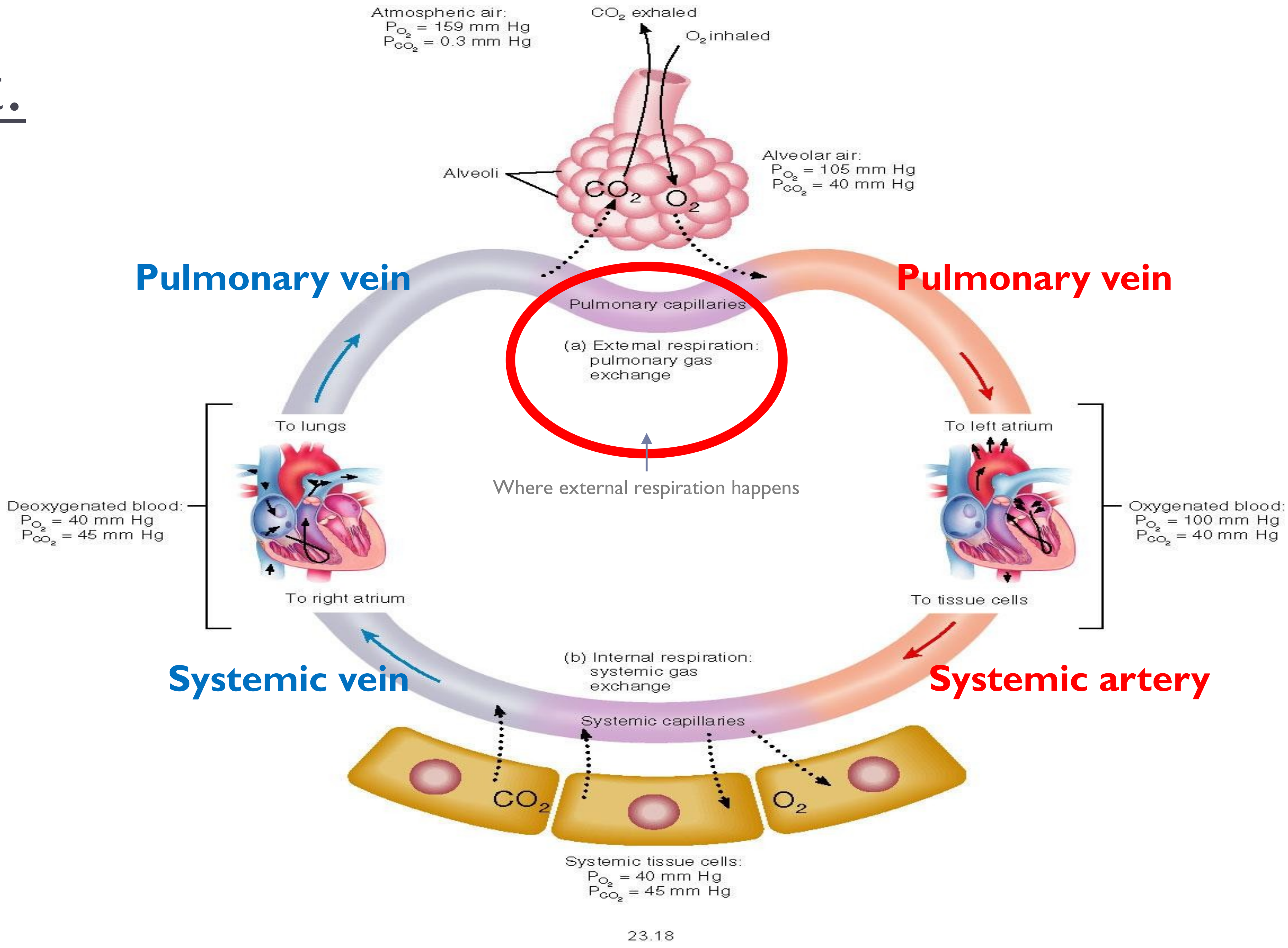
- Gas exchange happens between alveolus and capillaries that surround it.

- Both the alveoli and capillaries have to be patent (open) and functioning for gas exchange to occur.

- If one of them was not patent (collapsed), diffusion will not happen.



Cont.



Atmospheric air:
P_{O_2} = 159 mm Hg
P_{CO_2} = 0.3 mm Hg
CO_2 exhaled
O_2 inhaled
Alveoli
CO_2
O_2
Alveolar air:
P_{O_2} = 105 mm Hg
P_{CO_2} = 40 mm Hg
Pulmonary vein
Pulmonary vein
Pulmonary capillaries
(a) External respiration: pulmonary gas exchange
Where external respiration happens
To lungs
To left atrium
Deoxygenated blood:
P_{O_2} = 40 mm Hg
P_{CO_2} = 45 mm Hg
Oxygenated blood:
P_{O_2} = 100 mm Hg
P_{CO_2} = 40 mm Hg
To right atrium
To tissue cells
(b) Internal respiration: systemic gas exchange
Systemic vein
Systemic artery
Systemic capillaries
CO_2
O_2
Systemic tissue cells:
P_{O_2} = 40 mm Hg
P_{CO_2} = 45 mm Hg
23.18

Partial Pressure of Gases (in a Mixture)

- It is caused by: the constant kinetic movement of gas molecules against the surface.

- The 3 main gases (mixture) in respiratory physiology:

O_2, N_2, and CO_2.

- The rate of **diffusion** of each of these gases: is directly proportional with the partial pressure of the gas.

- Pressure of gases dissolved in water and tissue:

1. The **pressure** of gases dissolved in fluid is **similar** to their **pressure** in the gaseous phase and
2. They exert their own individual partial pressure.

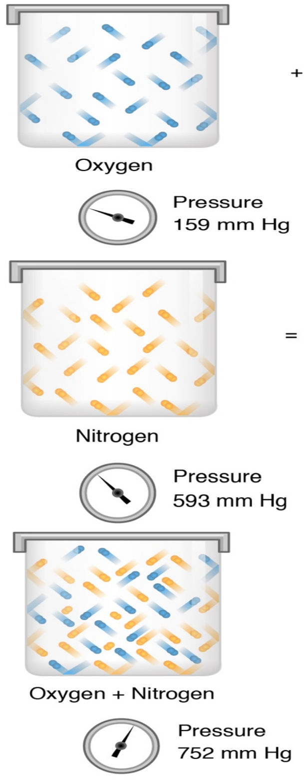
Gas Pressures in a Mixture of Gases—"Partial Pressures" of Individual Gases

Pressure is caused by multiple impacts of moving molecules against a surface. Therefore, the pressure of a gas acting on the surfaces of the respiratory passages and alveoli is proportional to the summated force of impact of all the molecules of that gas striking the surface at any given instant. This means that *the pressure is directly proportional to the concentration of the gas molecules.*

In respiratory physiology, one deals with mixtures of gases, mainly *oxygen, nitrogen,* and *carbon dioxide.* The rate of diffusion of each of these gases is directly proportional to the pressure caused by that gas alone, which is called the *partial pressure* of that gas. The concept of partial pressure can be explained as follows.

Consider air, which has an approximate composition of 79 percent nitrogen and 21 percent oxygen. The total pressure of this mixture at sea level averages 760 mm Hg. It is clear from the preceding description of the molecular basis of pressure that each gas contributes to the total pressure in direct proportion to its concentration. Therefore, 79 percent of the 760 mm Hg is caused by nitrogen (600 mm Hg) and 21 percent by O_2 (160 mm Hg). Thus, the "partial pressure" of nitrogen in the mixture is 600 mm Hg, and the "partial pressure" of O_2 is 160 mm Hg; the total pressure is 760 mm Hg, the sum of the individual partial pressures. The partial pressures of individual gases in a mixture are designated by the symbols PO_2, PCO_2, PN_2, PHe, and so forth.

Laws in Gas Exchange & Transfer



Video of (Partial Pressure)
Duration: (6:12) mins

Dalton's Law of Partial Pressures

States that:

The total pressure exerted by a mixture of gases is the sum of partial pressure of each individual gas present.

$$P_{total} = P1 + P2 + P3 + ..$$

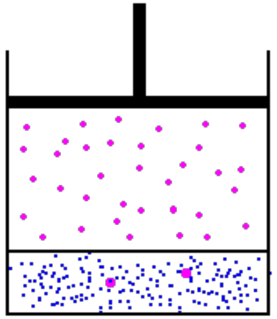
Henry's Law (of Solubility)

It state that:

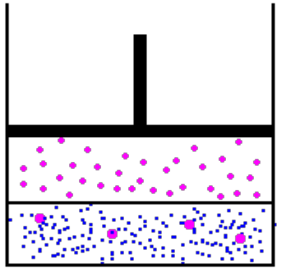
If the temperature stays constant , increasing the pressure will increase the amount of dissolved gas

Because: Gases in a liquid diffuse from higher partial pressure to lower partial pressure.

solubility (concentration) is directly proportional to the gas **partial pressure.**



Low pressure equilibrium
Low concentration



Double the pressure equilibrium
Double the concentration

Video of (Henry's Law)
Duration: (8:38)mins

ONLY IN FEMALES' SLIDES

Factors that Affect the Diffusion Rate of Gas Through the Respiratory Membrane

$$D = \alpha \frac{\Delta P \times A \times S}{d \times \sqrt{MW}}$$

D: diffusion rate

1. **P: Partial pressure differences (direct)**
2. **A: Surface area for gas exchange (direct)**
3. S: Solubility of gas (direct)
4. **d: diffusion distance** (thickness) **(inversely)**
5. MW: Molecular weight (inversely)

علاقة ال D طردية مع أي شيء في البسط و عكسية مع أي شيء في المقام.

- The **diffusion rate** of specific gases:
- Diffusion coefficient for the transfer of each gas through the respiratory membrane depends:
  - Directly on its solubility (S) through the membrane
  - Inversely on the square root of its molecular weight (MW).
- CO_2 diffuses 20 times as rapidly as O_2.

Factor that may also affect gas diffusion: (male slides)

Diffusion of coefficient of gas (directly)

Temperature	• Higher temperature → Diffuse Faster
Surface Area	• Larger surface → Diffuse Faster
Concentration Gradient	• Higher Gradient → Diffuse faster
Size of Particles	• Smaller particles → Diffuse faster
Diffusion Medium	• Solid → Slowest • Liquid → Faster • Gas → Fastest

Direct : Directly proportion (increase → increase) , Inversely proportion (increase → decrease) and vice versa.

Factors That Affect the Diffusion Rate of Gas Through the Respiratory Membrane

P: Partial Pressure Differences:

- The difference in gas pressure between the two sides of the membrane (between the alveoli and the capillary blood).
- This difference dictates the direction of diffusion:
  - **For Oxygen:** the pressure of the gas in the alveoli is greater than the pressure of the gas in the blood, so the gas will diffuse from the alveoli into the blood. (from high to low)
    - PO_2 in alveoli = 104, In blood = 40
  - **For CO2:** the pressure of the gas in the blood is greater than the pressure in the alveoli, net diffusion from the blood into the alveoli occurs.
    - PCO_2 in blood = 45, In alveoli = 40.

A: Surface Area of the Membrane:

- Average surface area is 70 m^2. in normal adult.
- Removal of an entire lung decreases the surface area to half normal.
- In emphysema (usually due to heavy smoking) with dissolution (loss) of the alveolar walls → decrease surface area to 5-folds.

D: Diffusion Distance (the Thickness of the Respiratory Membrane):

- Membrane thickness is almost 0.5 μm (very thin) and presents little obstacle to diffusion.
- If the membrane thickens, diffusion will take more time + gas exchange is inhibited (inversely proportional) like during exercise.
- Higher thickness like in edema, infection, or fluid effusion → lower rate of diffusion.
- **The thickness of the respiratory membrane is inversely proportional to the rate of diffusion through the membrane.**

Respiratory Unit

- Also called: respiratory lobule.
- Composed of: a respiratory bronchiole, alveolar ducts, atria, and alveoli.
- Number of alveoli in 2 lungs: about 300 million alveoli in the two lungs.
- Alveoli diameter: an average of 0.2 millimeters.
- Respiratory membrane thickness: in some areas it is as little as 0.2 micrometer, on average it is 0.6 micrometers.
- Total quantity of blood in the capillaries of the lungs: is (60 to 140 milliliters).

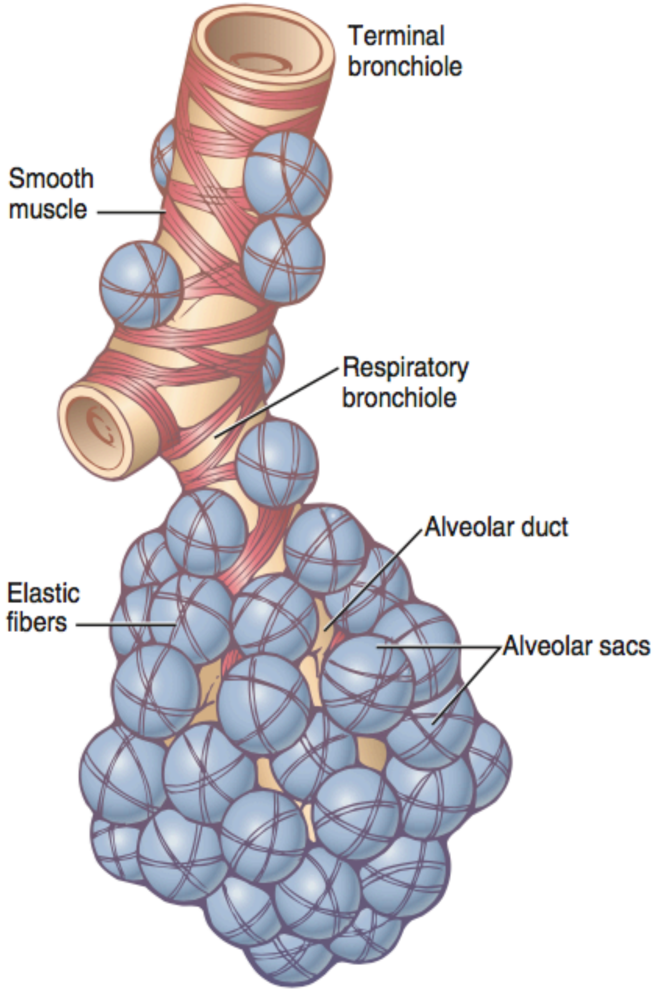
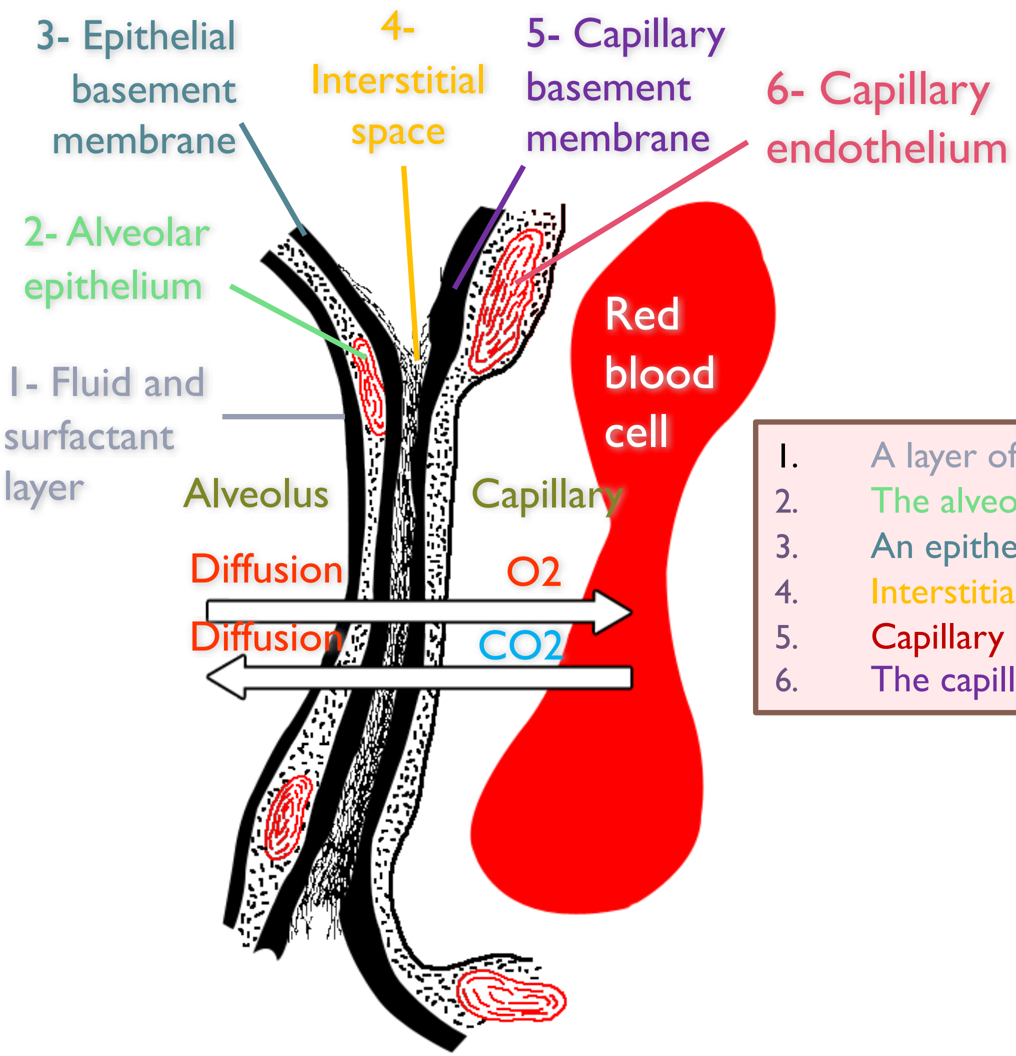


Figure 40-7. Respiratory unit.

Layers of Respiratory Membrane (Alveolus) From Inside Out



1. A layer of fluid lining the alveolus
2. The alveolar epithelium
3. An epithelial basement membrane
4. Interstitial space
5. Capillary basement membrane
6. The capillary endothelial membrane

Clearer picture:

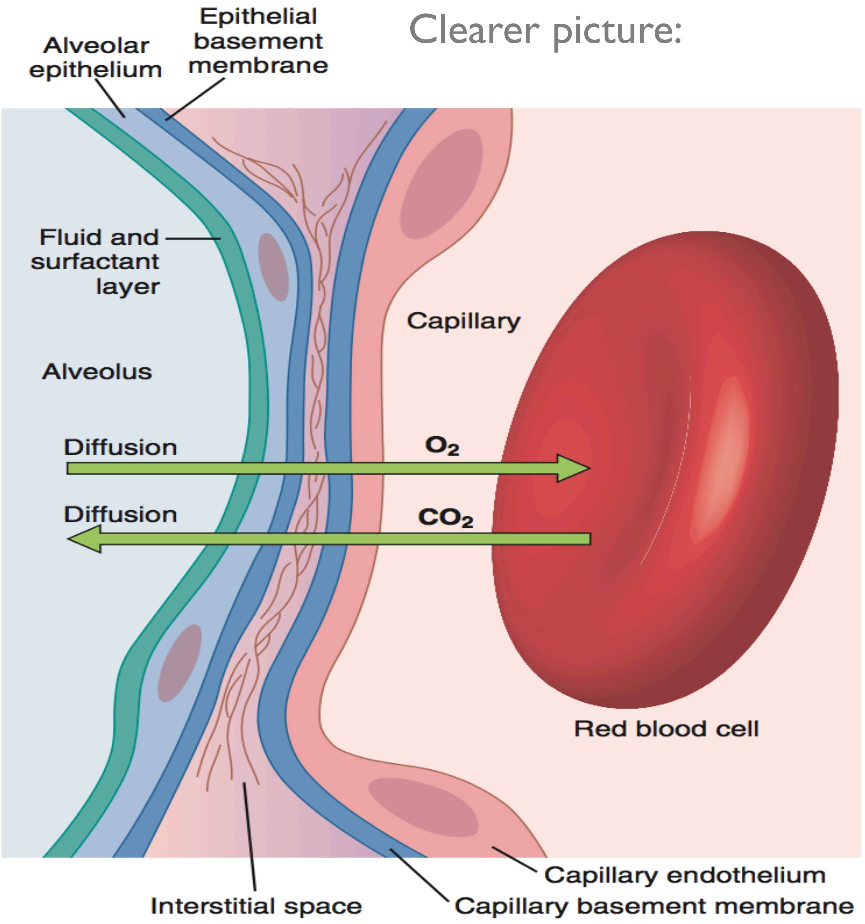


Figure 40-9. Ultrastructure of the alveolar respiratory membrane, shown in cross section.

Because of their partial pressures O2 and CO2 have opposite diffusion directions as we have mentioned previously.

Partial Pressures of Respiratory Gases as They Enter and Leave the Lungs (at Sea Level)

	N_2	O_2	CO_2	H_2O
Atmospheric Air (mmHg)	597.0 (78.62%)	159.0 (20.84%)	0.3 (0.04%)	3.7 (0.50%)
Humidified Air (mmHg) = conductive zone or anatomical dead space.	563.4 (74.09%)	149.3 (19.67%)	0.3 (0.04%)	47.0 (6.20%) Because it is humidified
Alveolar Air (mmHg) = respiratory zone.	569.0 (74.9%)	104.0 (13.6%)	40.0 (5.3%)	47.0 (6.2%)
Expired Air (mmHg)	566.0 (74.5%)	120.0 (15.7%)	27.0 (3.6%)	47.0 (6.2%)

O2 concentration in the atmosphere is 21%
PO2 in atmosphere = 760mmHg x 21% =160 mmHg.
This mixes with "old" air already present in alveolus to arrive at PO2 of 104 mmHg in alveoli. (drop)

CO2 concentration in the atmosphere is 0.04%
PCO2 in atmosphere = 760mmHg x 0.04% = 0.3 mmHg
This mixes with high CO2 levels from residual volume in the alveoli to arrive at PCO2 of 40 mmHg in the alveoli. (Increase)

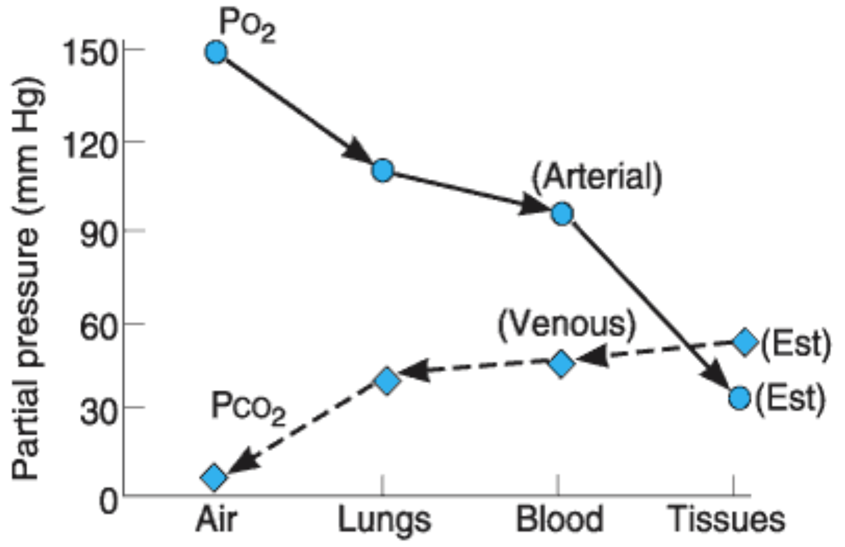
Composition of Alveolar Air and its Relation to Atmospheric Air

Further explanation of the previous schedule:

- Alveolar air is partially replaced by atmospheric air with each breath.
- O2 is constantly absorbed from the alveolar air. (reason of decrease)
- CO2 constantly diffuses from the pulmonary blood into the alveoli. (reason of increase)
- Once the dry atmospheric air enters the respiratory passage, it is humidified <u>before</u> it reaches the alveoli.

(as we studied in the function of conduction zone, or the function or respiratory mucosa)

Figure 35-1.



Summary of PO_2 and PCO_2 values in air, lungs, blood, and tissues, graphed to emphasize the fact that both O_2 and CO_2 diffuse "downhill" along gradients of decreasing partial pressure. (Redrawn and reproduced, with permission, from Kinney JM: Transport of carbon dioxide in blood. Anesthesiology 1960;21:615.)

PO2 and PCO2 in Various Potions of Normal Expired Air

PO2:

1. Diffusion from atmosphere into alveolus.

2. Diffusion from alveolus into pulmonary blood:

In Alveolus = 104

In venous (pulmonary) blood = 40

Pressure difference of O2 between alveoli and blood is : 014-40 = 64mmHg

3. Diffusion from Capillaries into interstitial fluid:

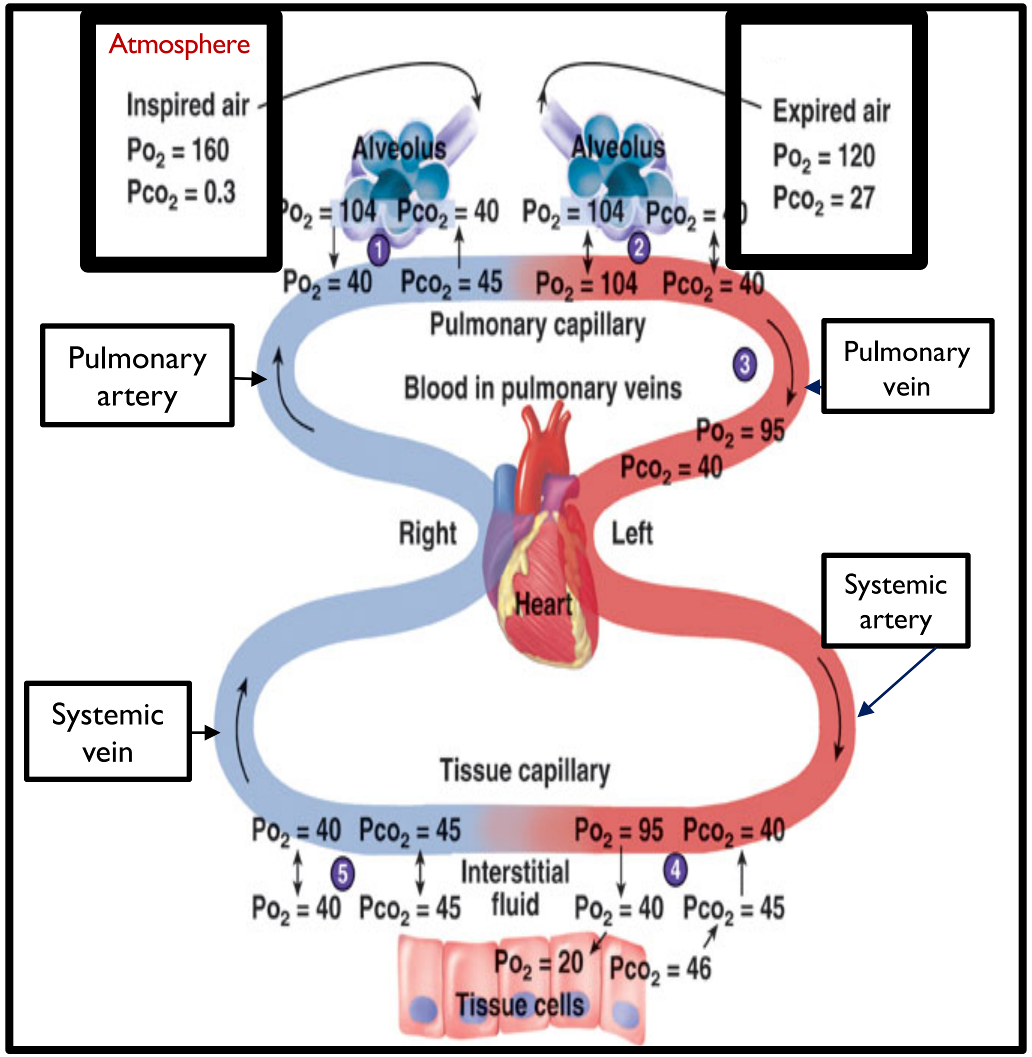
In arterial (end)blood = 95

In interstitial = 40

4. Diffusion from interstitial fluid into cells:

In interstitial = 40

Inside cell = 20 (females' slides) 23 (males' slides).



PCO2:

1. Diffusion from cell into interstitial fluid:

Inside cell = 46

In interstitial = 45

2. Diffusion from interstitial fluid into capillaries:

In interstitial = 45

In venous blood = 40

3.Diffusion pulmonary into alveoli:

In pulmonary blood = 45

In Alveolus = 40

4. Diffusion from alveolus into Atmosphere

Both happen in opposite directions.

Cont.

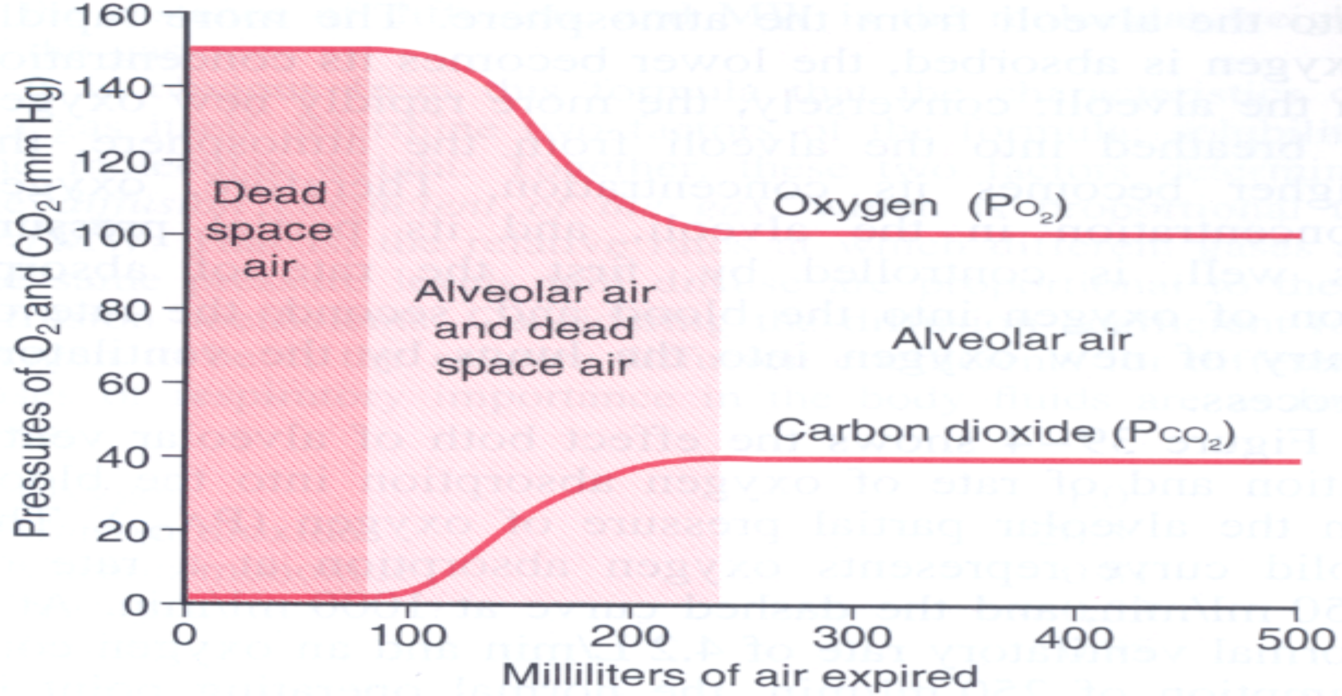


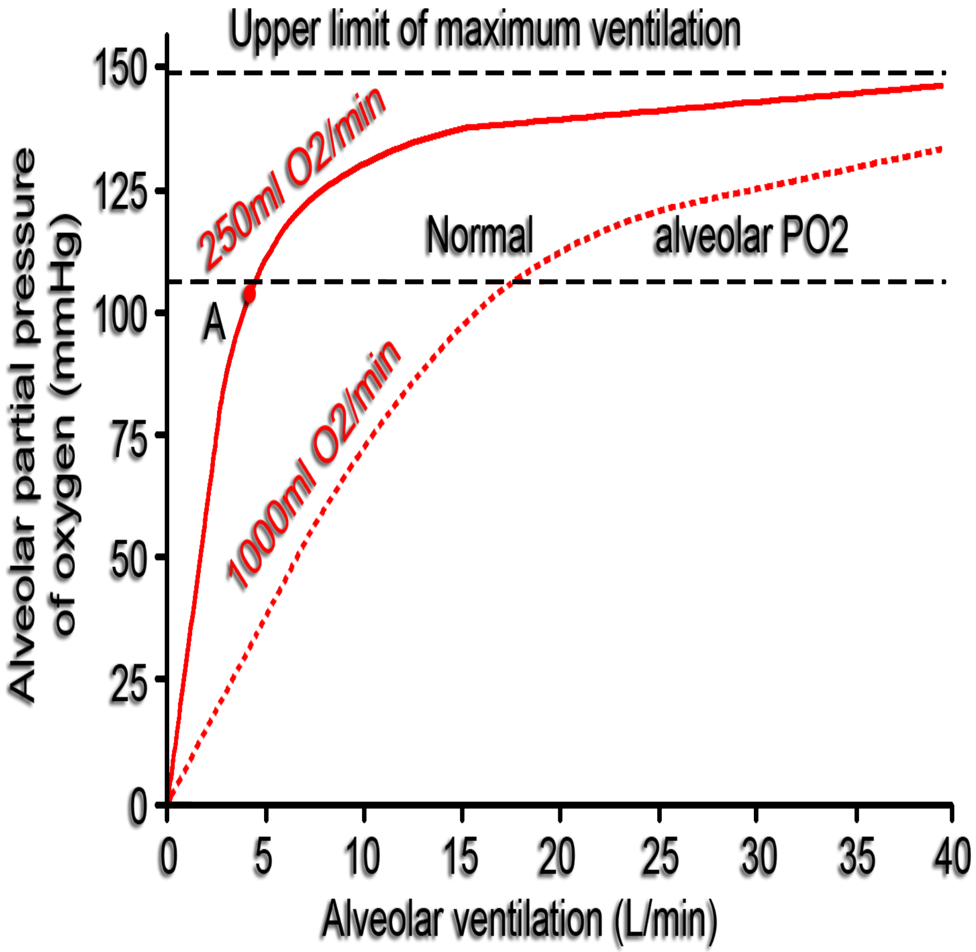
FIGURE 39 – 6

Oxygen and carbon dioxide partial pressures in the various portions of normal expired air.

Video of (Gas Diffusion) Duration: (12)mins

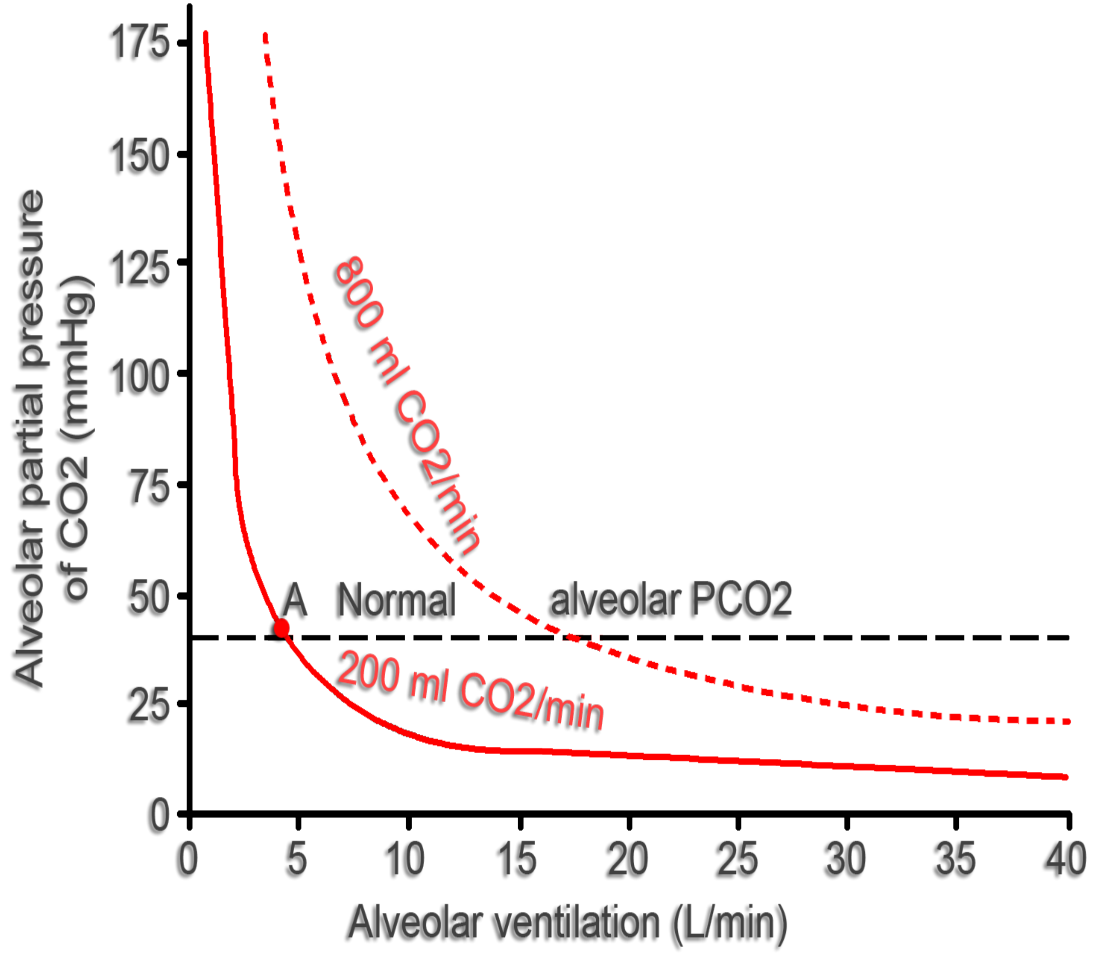
O_2 Concentrations in the Alveoli

- At resting condition: 250 ml of **oxygen** enters the pulmonary capillaries per minute (normal rate), as shown in the solid curve.
- At normal ventilation rate: 4.2 L/min.
- **Alveolar PO2** is at point A at 104 mmHg
- During exercise: 1000 ml of **oxygen** is absorbed by the pulmonary capillaries/min, as represented by the dotted curve.
- The alveolar (pulmonary) ventilation rate must increase 4 times (folds) to maintain the **alveolar PO2** (partial pressure) at the normal value of 104 mmHg.



CO2 Concentrations in the Alveoli

- At resting condition: 200ml of **CO2** is excreted per minute (normal rate), as shown in the solid curve.
- At normal ventilation rate: 4.2 L/min.
- The operating point for **Alveolar PCO_2** is at point A at 40mmHg.
- During exercise: 800 ml of **CO2** is excreted per minute, as represented by the dotted curve (Also 4 folds).
- **Alveolar PCO_2** increases directly in proportion to the rate of **CO_2 excretion.**
- **Alveolar PCO_2** decreases in inverse proportion to **alveolar ventilation.**



Quiz

- https://www.onlineexambuilder.com/gas-exchange-and-gas-transfer/exam-128880

Link to Editing File

(Please be sure to check this file frequently for any edits or updates on all of our lectures.)

References:

- Girls' and boys' slides.
- Guyton and Hall Textbook of Medical Physiology (Thirteenth Edition.)

Thank you!

اعمل لترسم بسمة، اعمل لتمسح دمعة، اعمل و أنت تعلم أن الله لا يضيع أجر من أحسن عملا.

The Physiology 436 Team:

Female Members:
Rana Barasain
Reema Alotaibi
Leena Alwakeel
Haifa Alshaalan

Male Members:
Mohammed Alayed
Fares alnafeesah

Team Leaders:
Qaiss Almuhaideb
Lulwah Alshiha

Contact us:
Physiology436@gmail.com
@Physiology436