MED437
KING SAUD UNIVERSITY

437
PHYSIOLOGY TEAM

Gas exchange and gas transfer

➢ Color index:

Red: important
Green: doctor's notes
Grey: extra information
Pink: found only in female's slides
Blue: found only in male's slides
Yellow: numbers

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Physiology 437 teamwork

Editing file

objectives:

'Armando' 13:51
Overview for this
lecture and the
coming one

By the end of the lecture you will be able to:

(1) Define partial pressure of a gas.

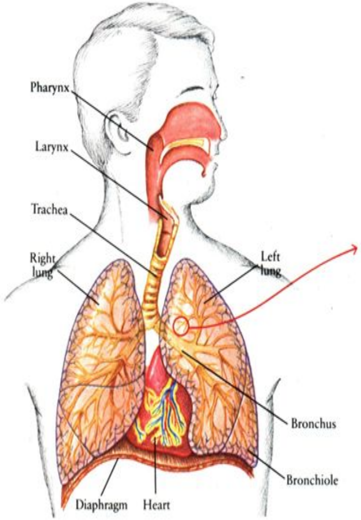
(2) Understand that the pressure exerted by each gas in a mixture of gases is dependent on the pressure exerted by the other gases (Dalton's Law).

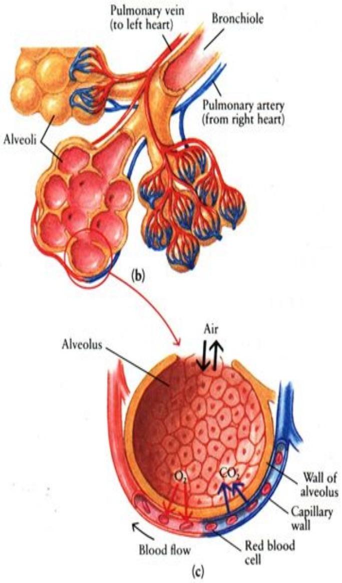
(3) Understand that gases in a liquid diffuse from higher partial pressure to lower partial pressure (Henry's Law) Describe the factors that determine the concentration of a gas in a liquid.

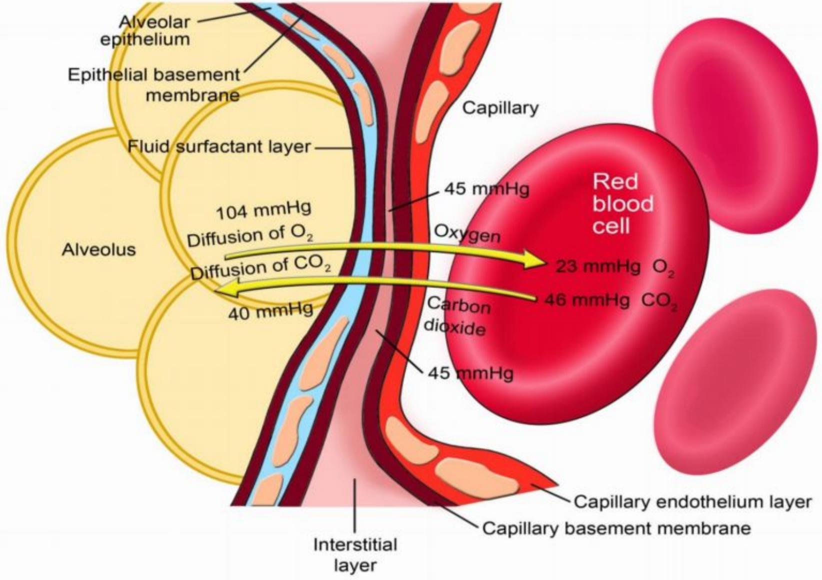
(4) Describe the components of the alveolar-capillary membrane (i.e., what does a molecule of gas pass through).

(5) Knew the various factors determining gas transfer: - Surface area, thickness, partial pressure difference, and diffusion coefficient of gas.

(6) 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.

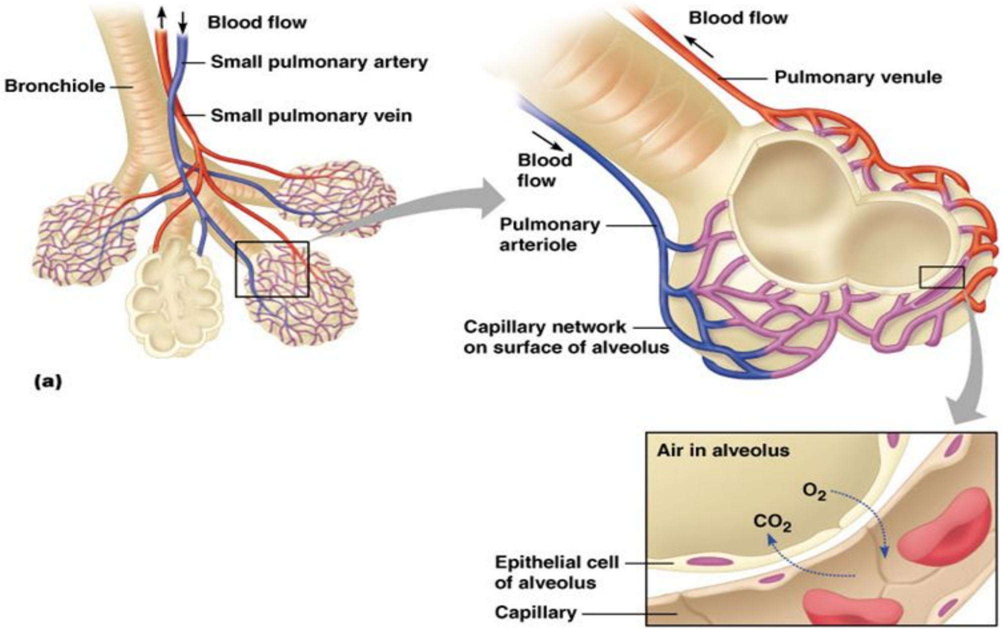

Pharynx
Larynx
Trachea
Right lung
Left lung
Bronchus
Bronchiole
Diaphragm
Heart


Pulmonary vein
(to left heart)
Bronchiole
Pulmonary artery
(from right heart)
Alveoli
(b)
Air
Alveolus
O_2
CO_2
Wall of alveolus
Capillary wall
Red blood cell
Blood flow
(c)


Alveolar epithelium
Epithelial basement membrane
Capillary
Fluid surfactant layer
45 mmHg
Red blood cell
104 mmHg
Diffusion of O_2
Alveolus
Oxygen
Diffusion of CO_2
23 mmHg O_2
46 mmHg CO_2
40 mmHg
Carbon dioxide
45 mmHg
Capillary endothelium layer
Capillary basement membrane
Interstitial layer

Gas exchange through the respiratory membrane

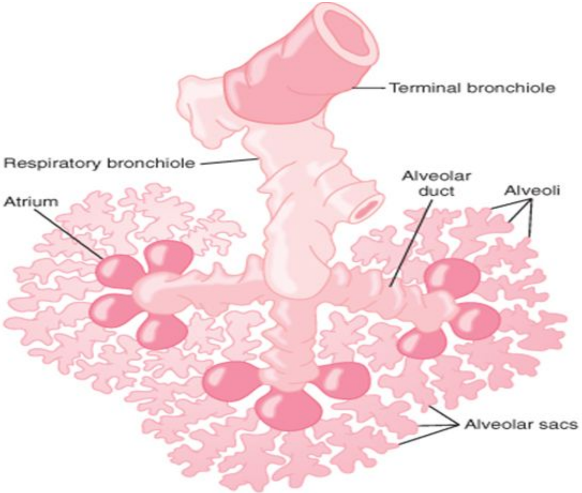
- Gas exchange happens at the level of the alveolus and the capillaries that surround them,
- so both the capillaries and alveoli have to be patent (not collapsed) and fully functioning in order for gas transfer to take place.



RESPIRATORY UNIT

Respiratory Unit:

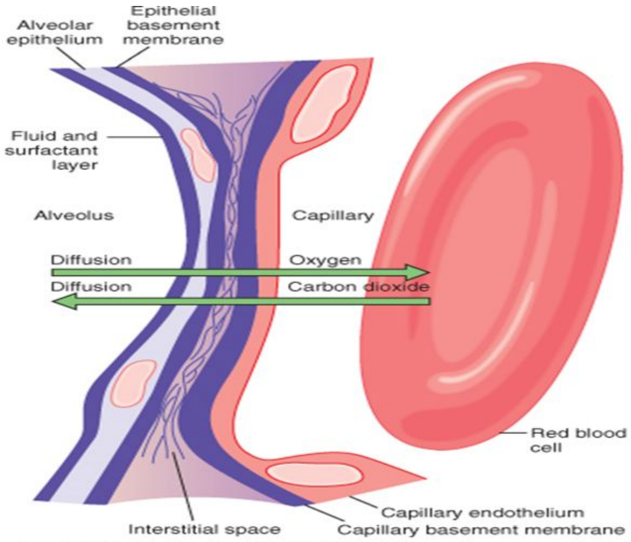
- Also called **“respiratory lobule”**
- composed of : 1- a respiratory bronchiole, 2- alveolar ducts, 3- atria, 4-alveoli.
- There are about 300 million alveoli in the two lungs, and each alveolus has an average diameter of about 0.2 millimeter.
- The alveolar walls are extremely thin, and between the alveoli is an almost solid network of interconnecting capillaries.



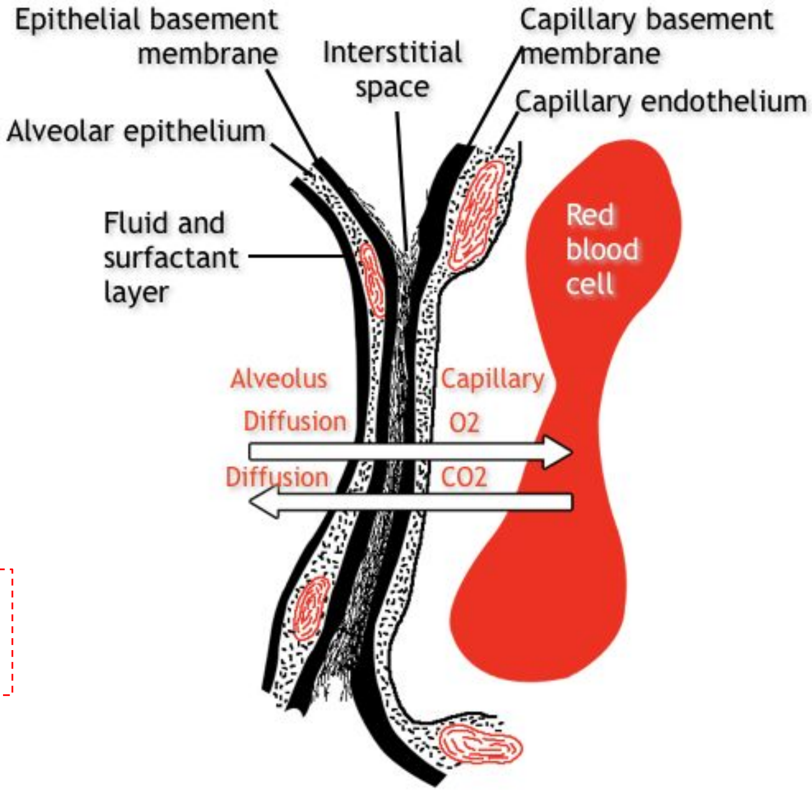
LAYERS OF THE RESPIRATORY MEMBRANE

Diffusion of oxygen from the alveolus into the red blood cell and diffusion of carbon dioxide in the opposite direction. Note the following different layers of the respiratory membrane:

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

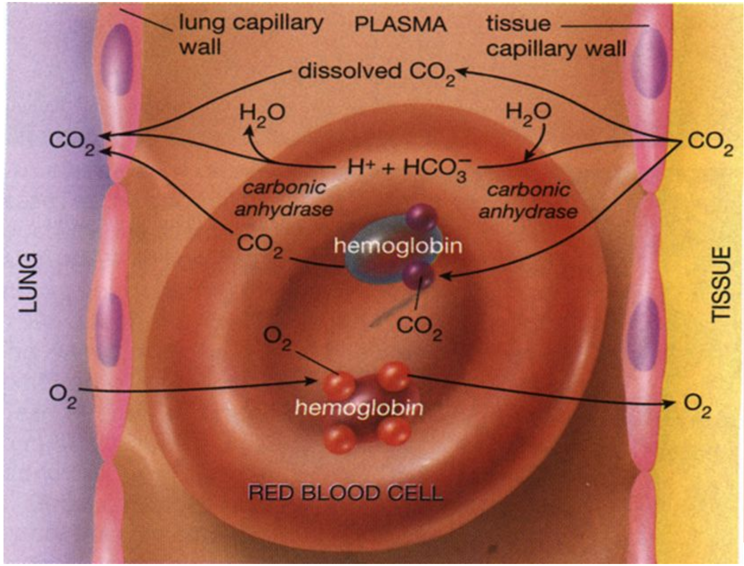


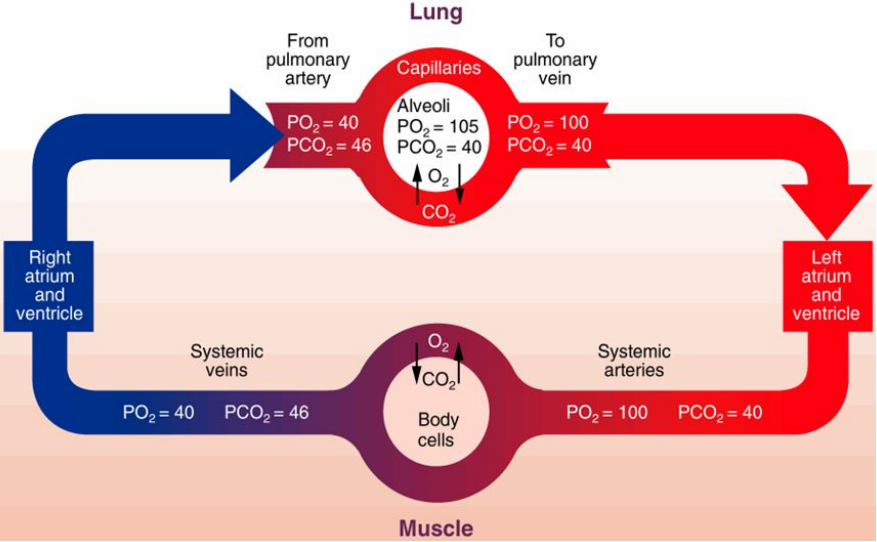
The different layers of the respiratory membrane:
1-the fluid and surfactant that lines the alveoli.
2- alveolar epithelium
3-alveolar basement membrane.
4- interstitium.
5- capillary basement membrane
6- capillary endothelium.



There is always
a question
from this slide

Partial pressure of gases





Only in Female's slides

Partial pressure of gases (in a mixture)

- The pressure of gas is caused by the constant kinetic movement of gas molecules against the surface. كمية الحركة(الصدمات) لجزيئات الغاز الي تسويها على سطح ما
- In respiratory physiology, there is a mixture of gases mainly of 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. كل غاز حركته تسب بكمية ضغط محددة

Pressure of gases dissolved in water and tissue: The pressure of gases dissolved in fluid is similar to their pressure in the gaseous phase and they exert (تبذل) their own individual partial pressure.

As partial pressures increases , the rate of diffusion through the respiratory membrane increases.

غايتون هنا شرحها بشكل مبسط وجميل

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 P_{O_2}, P_{CO_2}, P_{N_2}, P_{He}, and so forth.

Laws in gas exchange & transfer

Watch till 4:15

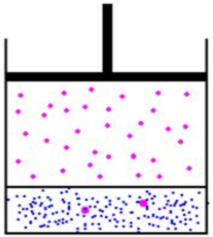
Dalton’s law of partial pressure

- It states that the total pressure exerted by a mixture of gases is the sum of partial pressure of each individual gas present.

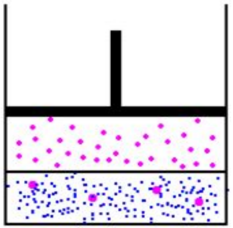
- Ptotal = P1 + P2 + P3 + . . .

Henry’s law of Gas solubility

- Gas solubility is proportional to the gas partial pressure. If the temperature stays constant increasing the pressure will increase the amount of dissolved gas.



Low pressure equilibrium
Low concentration



Double the pressure equilibrium
Double the concentration

Factors that affect the rate of gas diffusion through the respiratory membrane

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

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

Important to know the factors and its relation to diffusion (directly OR inversely)

The diffusion rate of the specific gas:

- Diffusion coefficient for the transfer of each gas through the respiratory membrane depends on:

بناخذ بعد شوي أن الكربون

  - Directly on partial pressure
  - 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. (if we have diffusion failure , O2 will be affected more)

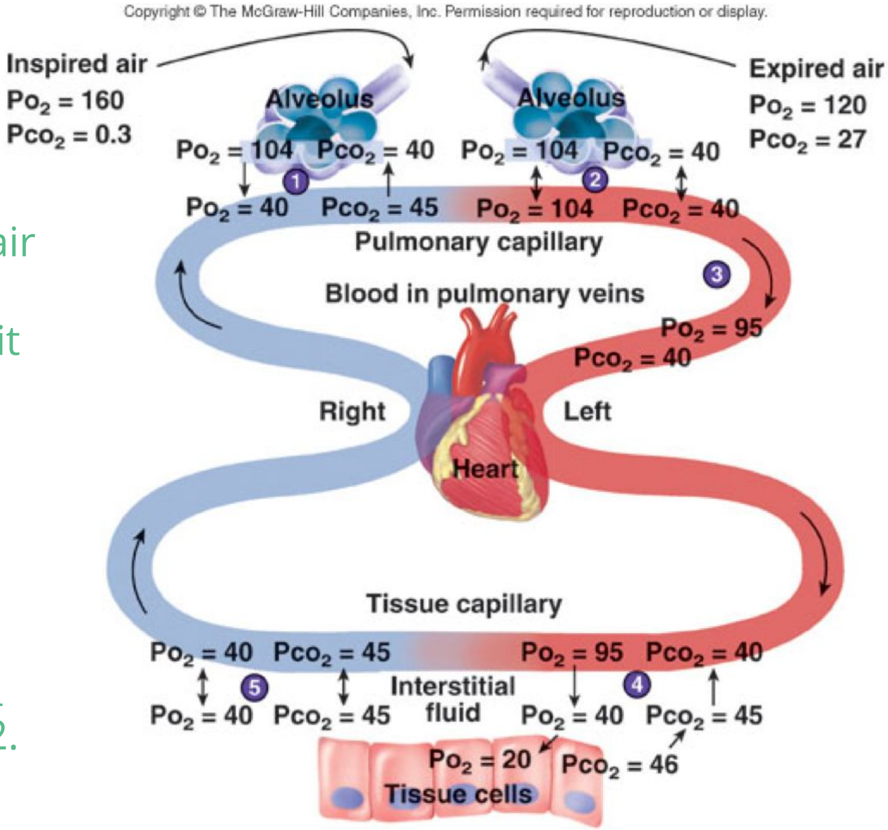
لماذا ؟ هنا المحدد هو خواص CO2 الكيميائية تساعده أكثر بعشرين مرة (الخواص الكيميائية أو الdiffusion coefficint لوحدها نقصد بها (S/√M

Other factors affect gas diffusion:

Factors that affect the rate of gas diffusion through the respiratory membrane

P: Partial pressure differences The pressure difference between the two sides of the membrane (between the alveoli and the blood).	**(A):** Surface area of the membrane.	**(D:Diffusion distance)** The thickness of the respiratory membrane
When the pressure of the gas in the alveoli (PO2= 104) is greater than the pressure of the gas in the blood (PO2=40) as for O_2, net diffusion from the alveoli into the blood occurs.	Removal of an entire lung decreases the surface area to half normal.	↑ thickness of the respiratory membrane e.g., edema ⟶ ↓ rate of diffusion (inversely proportional).
When the pressure of the gas in the blood(PCO2=45) is greater than the pressure in the alveoli (PCO2=40) as for CO_2, net diffusion from the blood into the alveoli occurs.	In emphysema with dissolution of the alveolar wall ↓ Surface.Area. → to 5-folds because of loss of the alveolar walls.	The thickness of the respiratory membrane is inversely proportional to the rate of diffusion through the membrane.

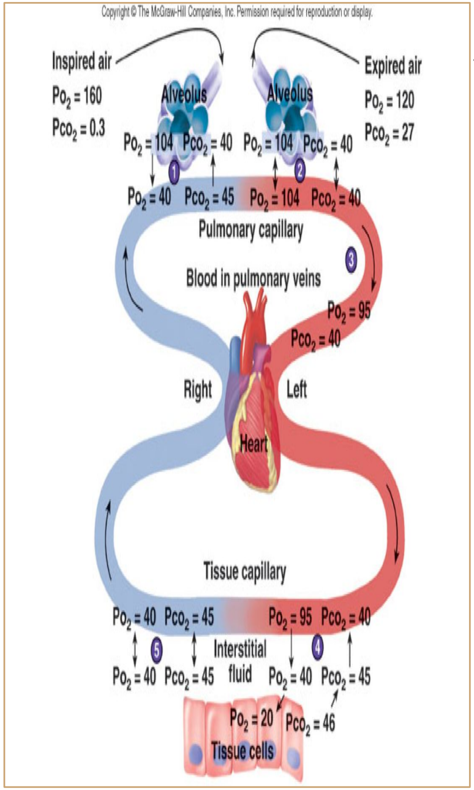
- The partial pressure of oxygen in the inspired air starts off as 160 and <u>decreases gradually</u> as it passes around the systemic circulation because most of it will diffuse to the tissues , finally reaching a concentration of 120 in the expired air. And <u>the opposite</u> is true for CO2.



Diffusion of Oxygen

1. **Diffusion from atmosphere into alveolous**
2. **Diffusion of oxygen from alveoli into pulmonary blood:** PO2 in the alveolus = 104 mmHg, PO_2 of the venous blood = 40 mmHg since a large amount of O_2 has been removed from blood as it passes through the peripheral pulmonary capillary is 104-40 = 64 mmHg.
3. **Diffusion of O_2 from capillaries into interstitial fluid:** PO_2 in the capillaries =95 mmHg in interstitial fluid = 40 mmHg. Therefore O_2 diffuses from arterial end of capillary into the interstitial fluid.
4. **Diffusion of O_2 from interstitial fluid into cells:** PO_2 in interstitial fluid =40 mmHg PO_2 in the cells =23 mmHg therefore O_2 diffuses from interstitial fluid into the cells.

Important slide



DIFFUSION OF CO_2

The diffusion of $\mathbf{CO_2}$ occurs in <u>the opposite direction</u> of oxygen. It diffuses from the cells to the interstitial fluid and to alveoli

1. **Diffusion of CO_2 from cells to interstitial fluid:** P**CO_2** within the cell =46 mm Hg, P**CO_2** in the interstitial fluid =45 mm Hg. Thus it diffuses from the cells to the interstitial fluid.
2. **Diffusion of CO_2 from interstitial fluid into capillaries:** P**CO_2** in interstitial fluid =45 mm Hg, while in the arterial end of the capillaries=40 mm Hg. Therefore, **CO_2** diffuses from interstitial fluid into the capillaries.
3. **Diffusion of CO_2 from pulmonary blood into alveoli:** P**CO_2** in pulmonary blood = 45 mm Hg, while in the alveolus, it is 40 mm Hg. So **CO_2** diffuses from pulmonary blood into the alveoli.
4. **Diffusion from alveolous into atmosphere**

Only in Female's slides

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)	563.4 (74.09%)	149.3 (19.67%)	0.3 (0.04%)	47.0 (6.20%)
Alveolar Air (mmHg)	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%)

- Oxygen concentration in the atmosphere is 21%
- So PO_2 in atmosphere =760 mmHg x 21%= 160 mmHg.
- This mixes with "old" air already present in alveolus to arrive at PO_2 of 104 mmHg in alveoli.

- Carbon dioxide concentration in the atmosphere is 0.04%
- So PCO_2 in atmosphere =760 mmHg x 0.04% = 0.3 mm Hg
- This mixes with high CO_2 levels from residual volume in the alveoli to arrive at PCO_2 of 40 mmHg in the alveoli.

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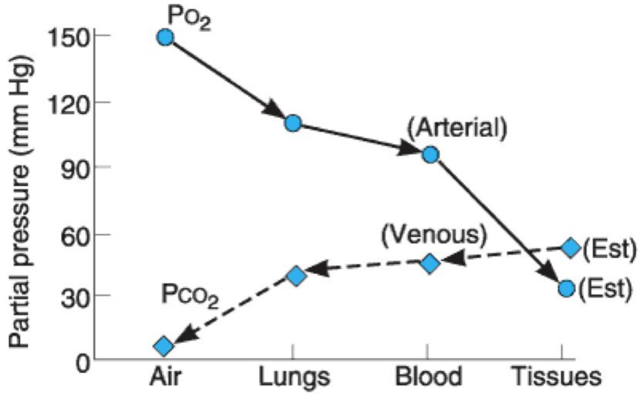
Composition of alveolar air and its relation to atmospheric air

Why Alveolar air does not have the same concentrations of gases as atmospheric air (see the table in previous slide) ?

1. Alveolar air is partially replaced by atmospheric air with each breath.
2. O_2 is constantly absorbed from the alveolar air.
3. CO_2 constantly diffuses from the pulmonary blood into the alveoli.
4. The dry atmospheric air enters the respiratory passage is humidified before it reaches the alveoli.

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.)

Only in Female's slides

PO2 and PCO2 in various positions of normal expired air

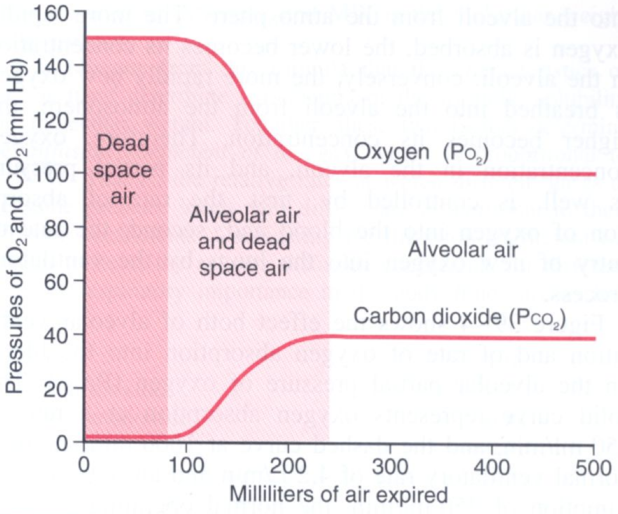


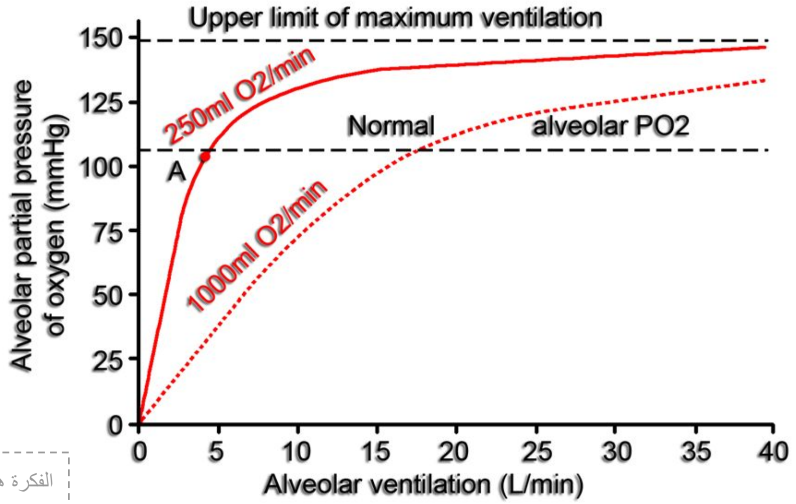
FIGURE 39-6

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

Only in Female's slides

O2 concentration in the alveoli

- At resting condition 250 ml of oxygen enter the pulmonary capillaries/min at ventilatory rate of 4.2 L/min. (tidal volume '500'- dead space '150')x respiratory rate '12' = 4200 ml/min.
- During exercise 1000 ml of oxygen is absorbed by the pulmonary capillaries per minute, the rate of alveolar ventilation must increase 4 times to maintain the alveolar PO_2 at the normal value of 104 mmHg.



الفكرة هي أن تركيز الاكسجين يتعمد على شيئين :

1) the rate of absorption of O2 into the blood

2) the rate of entry of new O2 into the lungs by the ventilatory process.

في وضع الراحة الجسم ما يحتاج اكسجين عشان كذا ما يستهلك الا 250ml كل دقيقة ، بينما في التمرين الجسم يحتاج اكسجين عالي 1000ml كل دقيقة فعشان يوازن تركيز الاكسجين وPO2 بعد ارتفاع الابزوربشن لازم يرفع الفنتليشن "ادخال الهواء للرئة"

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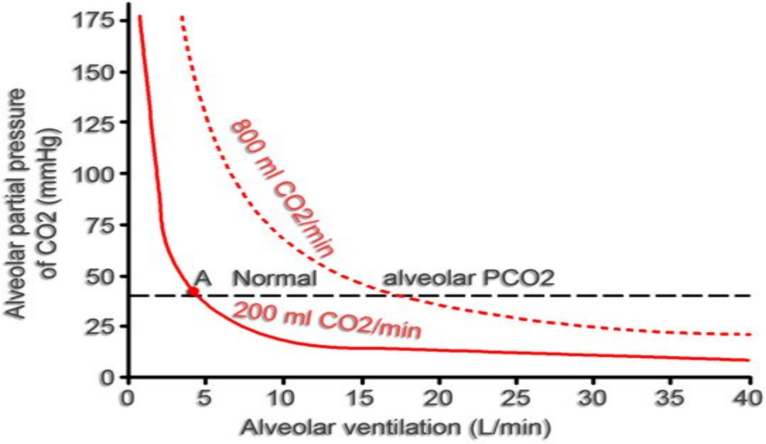
CO_2 concentration in the alveoli

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



Female’s team:

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Members:

Ahad Ahmed AlGrain.

Rinad Alghoraiby

Lina Alohali

Maha Alnahdi

Hadeel Awartani

Sarah AlFlaij

Munira Al Hadlaq

Male’s team:

Leader: Abdulhakim AlOnaiq

Members: