Physiology Team 432

5^{th} Lecture

Gas Transfer (Diffusion of O_2 and CO_2)

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OBJECTIVES

1-Define partial pressure of a gas, how is influenced by altitude.

2- Understand that the pressure exerted by each gas in a mixture of gases is independent of 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).

4- Describe the factors that determine the concentration of a gas in a liquid.

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

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

7- 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 pulmonarycapillary.

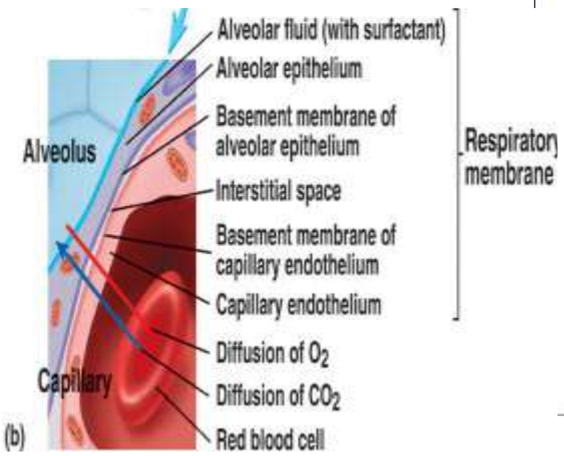
Definitions:

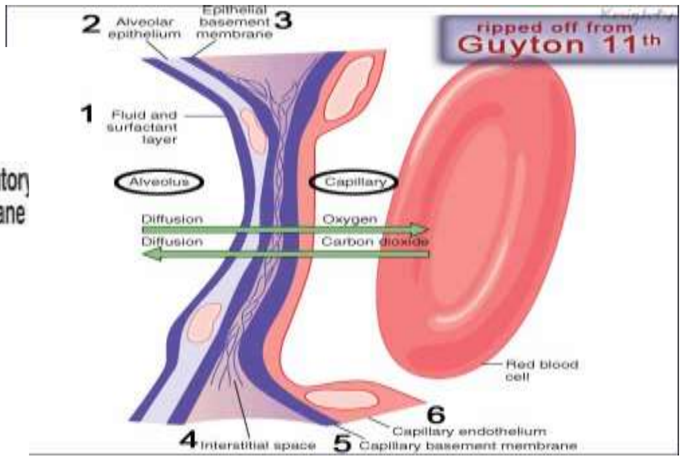
-partial pressure: pressure exerted by **one** of the gases in a **mixture,** for example the pressure of oxygen in the atmosphere, it is called partial pressure of oxygen (PO2), the oxygen is **one** of the mixture gases in the atmosphere).

-MmHg: millimeter of mercury, a pressure unit (atmospheric pressure= 760 mmHg.

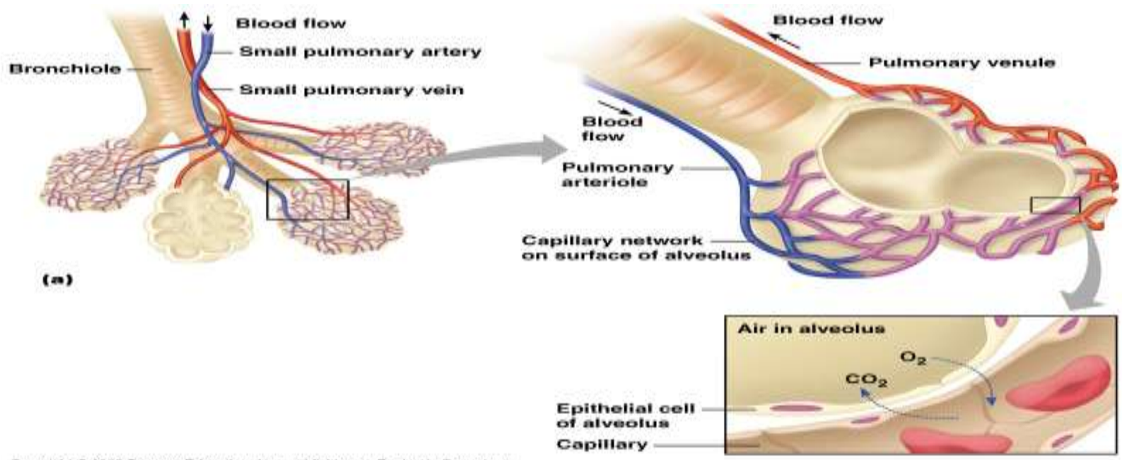
-Diffusion of gases: transfer of gases from high concentration to low concentration.

-Respiratory membrane (Alveolar-capillary membrane) : alveolar epithelium , capillary endothelium and in between the interstitial tissue.
(Dr. Ashraf prefers the name alveolar-capillary membrane since it is more accurate.

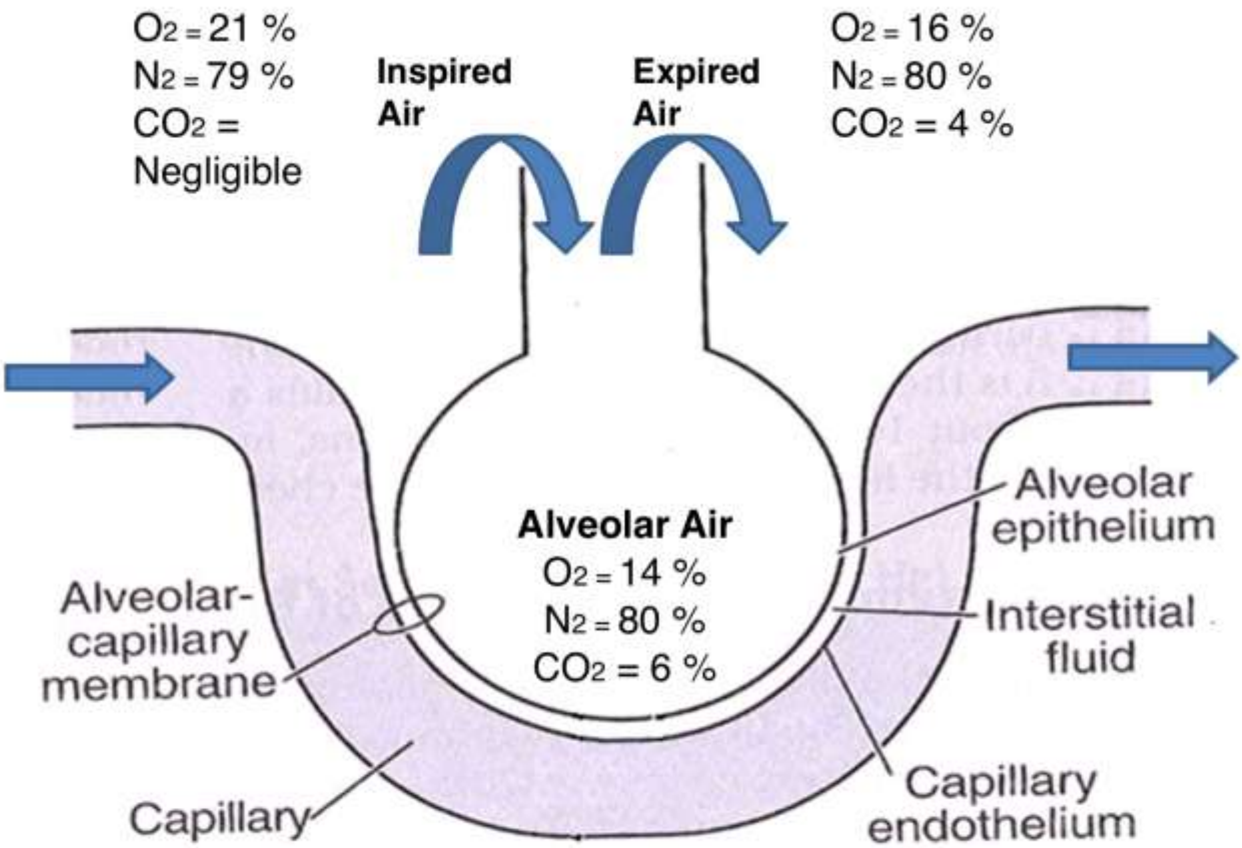




Gas exchange through the respiratory membrane:



The alveoli are polyhedral in shape which increase the surface area for gas exchange in the lung (50-100 m^2)



Percentage composition of Gases involved during breathing

From the picture we can see that O_2 is decreased and CO_2 is increased in the alveolar air because oxygen is consumed and Carbon dioxide is produced and when the remaining O_2 is expired it increases; simply because alveolar oxygen is less than atmospheric oxygen and when mixing low oxygen gradient with rich oxygen gradient the low oxygen gradient become more.

At rest, RBCs remain in pulmonary capillaries for 0.75 s. This time is known as capillary transit time.

It becomes less during exercise and may be 0.25 s.

*The **rate of diffusion** of these gases is directly proportional tothe **pressure caused by this gas alone** which is called the partial pressureof the gas ,so partial pressure and diffusion are directly proportional

*what cause the pressure ??

Pressure is caused by the constant impact of kinetically moving molecules against a surface

Factors affecting gas diffusion :

1. P: Partial pressure differences (directly proportional)
2. A: Surface area for gas exchange (directly proportional)
3. d: Diffusion distanceor membrane thickening (Inversely proportional)
4. MW: Molecular weight (Inversely proportional) and (S) solubility of gas (directly proportional).

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

- O_2 has lower molecular weight than CO_2
- But CO_2 is 24 times more soluble than O_2
- Net result: CO_2 diffusion approx 20 times faster than O_2

Diffusion coefficient:

S/√MW is called *the diffusion coefficient* of the gas.
For Oxygen = 1.0 carbon dioxide =20.0 nitrogen=0.53.
at the same pressure : different gases will diffuse according to their diffusion coefficient(directly proportional)

Diffusion coefficient ⟶ ↑ Diffusion

Diffusion capacity of the diffusion membrane:

(is the volume of gas that diffuses through themembrane each minute for a pressure difference of1mmHg) .
**Unite of diffusion capacity: ml/min/mmHg

لو كان فرق الضغط بين غشائين (alveoli & capillary) ثابت ويساوي 1mmHg نحسب خلال دقيقة الكمية أو الحجم ml بالملي لتر الذي سيعبر من أحد الغشائين إلى الأخر . من التجارب وُجد أنها (21) ml/min/mmHg

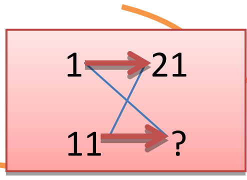
Diffusing capacity for oxygen21ml/min/mmHg:

- Even if the oxygen pressure difference across the respiratory membrane is 11mmHg----------11x21= 230ml oxygen diffusing through the membrane each minute>
- During rest tissues consume 250 ml O2 /min

لكن القيمة الحقيقية لفرق الضغط بداخل أجسامنا =11mmHg

وبما أننا وجدنا إن لكل 1 فرق ضغط 21ml بالتالي لو أردنا حساب حجم الغاز الذي سينتقل خلال 11 فرق ضغط فإننا نضرب 21 في 11(وسطين في طرفين)

يعني أن الجسم يحتاج 230 لكنه يأخذ أكثر من حاجته 250



The Carbon monoxide method for measuring diffusing capacity of Oxygen: (From Dr Ashraf)

Since measurement of diffusing capacity of oxygen directly is difficult due to imprecise measurement of PO_2, we use CO in small amount to measure it indirectly by using the formula:

$$Vgas = \underbrace{\frac{A}{d}}_{DL} \times D(P_1 - P_2)$$

- V gas: Volume of gas per time
- A: Area
- d: thickness
- D: Diffusion coefficient
- P_1: Alveolar partial pressure of gas
- P_2: partial pressure in capillaries
- DL: diffusion capacity of the gas

And because CO combine with the hemoglobin so rapidly; that its pressure in capillaries doesn't have time to build up, the value of P_2 equals to zero. So:

$$Vgas = DL \times P_1 \Rightarrow DL = \frac{Vgas}{P_1} = 17ml/\min/mmHg$$

And because diffusion coefficient of O is 1.23 times the diffusion coefficient of CO we multiply 17 by 1.23 to convert diffusion capacity of CO into Diffusion capacity of Oxygen which is 21 ml/min/mmHg

Changes of diffusion capacity during exercise:

65ml/min/mmHg

This is due **to:**

1- increased number of open pulmonary capillaries which was dormant, thereby increasing the surface area for gas exchange.

2- increased alveolar ventilation

3- During exercise the oxygen requirement increased 20 times, and cardiac output increased and so the time blood remained in the pulmonary capillaries becomes less than half normal despite the fact that additional capillaries open up But the blood is almost completely saturated withoxygen when it leaves the pulmonary capillaries

Passage of blood faster will not affect oxidation because the one third of time taken during rest is sufficient

1mmHg → 21ml/min/mmHG

	O_2 Pressure difference	O_2 Volume diffuse
During rest	1 mmHg	21 ml/min/mmHg
During exercise	1 mmHg	65ml/min/mmHg

Chang in diffusion capacity of CO_2:

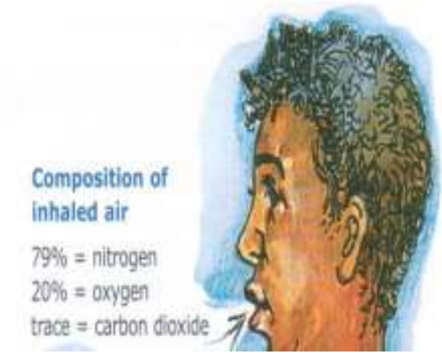
- it diffuses 20 times greater than oxygen due to greater Diffusion coefficient which is 20 times that for oxygen.
- Diffusion capacity for carbon dioxide 400ml/min/mmHg (for O2 it was 21 and multiplied by 20 because CO2 diffuse 20 times greater than O2).
- during exercise 1200 to 1300ml/min/mmHg

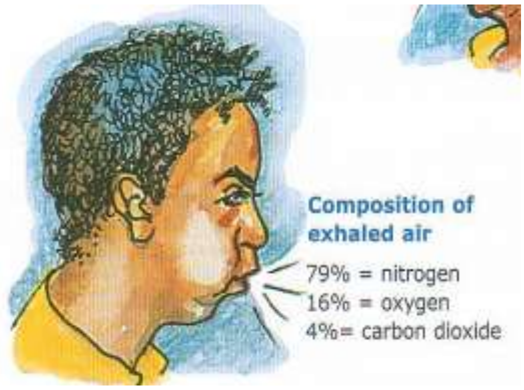
	CO_2 Pressure difference	CO_2 Volume diffuse
During rest	1 mmHg	(21*20)~400ml/min/mmHg
During exercise	1 mmHg	(65*20)1200~ml/min/mmHg

Reasons of these areas follow:

1-The diffusing capacity for oxygen increases almost three fold during exercise, this results mainly from increasing numbers of capillaries participating in the diffusion, and a more even V/Q (ventilation/perfusion or pulmonary blood flow) ratio all over the lung.

2- At rest the blood normally stays in the lung capillaries about three times (it was 21ml and then 65ml during exercise so we multiplied by 3) as long as necessary to cause full oxygenation. Therefore, even with shortened time of exposure in exercise, the blood is still fully oxygenated or nearly so.





Partial pressure ofO2 and CO2:

*Oxygen **concentration** in the atmosphere is 21% from total atmospheric c So PO_2 (partial pressure of O_2) in atmosphere = 760 mmHg (x 21% = **160** mmHg.

- This mixes with "old" air already present in alveolus to arrive at PO2 of **104** mmHg in alveoli.

*Carbon dioxide **concentration** in the atmosphere is 0.04%
So PCO_2 (partial pressure of CO2)in atmosphere =760 mmHg x 0.04% = **0.3** mm Hg

- This mixes with high CO2 levels from residual volume in the alveoli to arrive at PCO2 of **40** mmHg in the alveoli.

PO2 in atmosphere 160 once it enter the body it decrease to 104,,,PCO2 in atmosphere 0.3 once it enter the body it increase to 40

Partial pressure of gases in inspired air and alveolar:

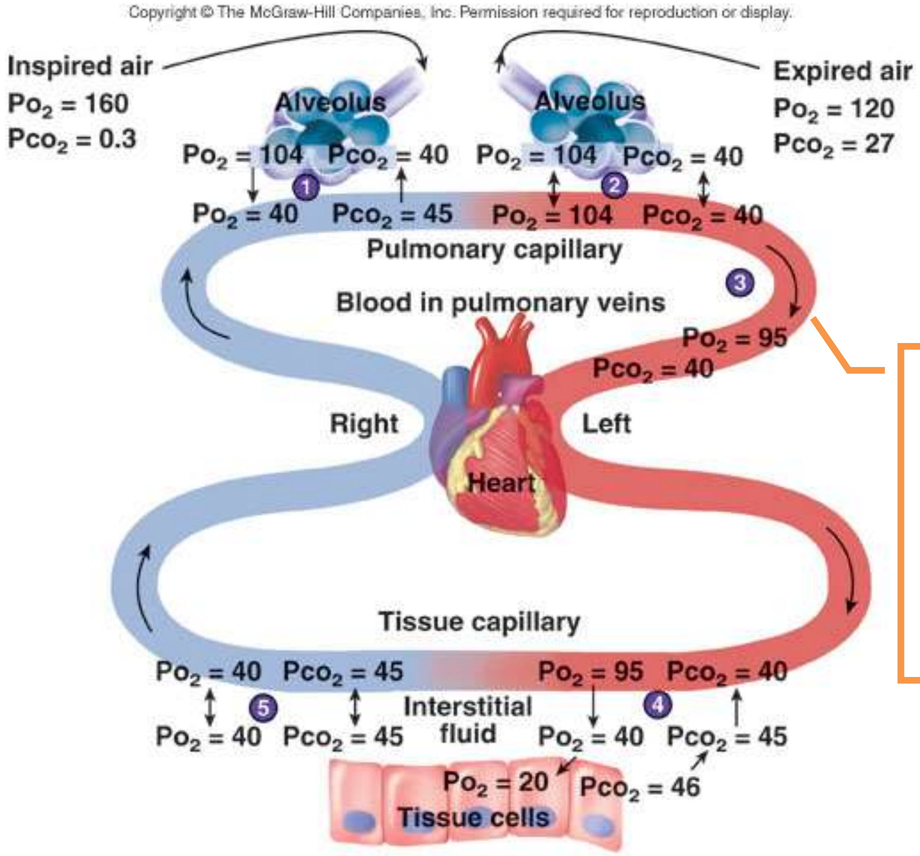
	Inspired air	Alveolar air
H_2O	Variable	47 mmHg
CO_2	000.3 mmHg	40 mmHg
O_2	159 mmHg	105 mmHg
N_2	601 mmHg	568 mmHg
Total pressure	760 mmHg	760 mmHg

This partial pressure of alveolar H_2O is called water vapor pressure
.

Dry pressure is determined by subtracting vapor pressure from total alveolar pressure that is:

760-47=713 mmHg

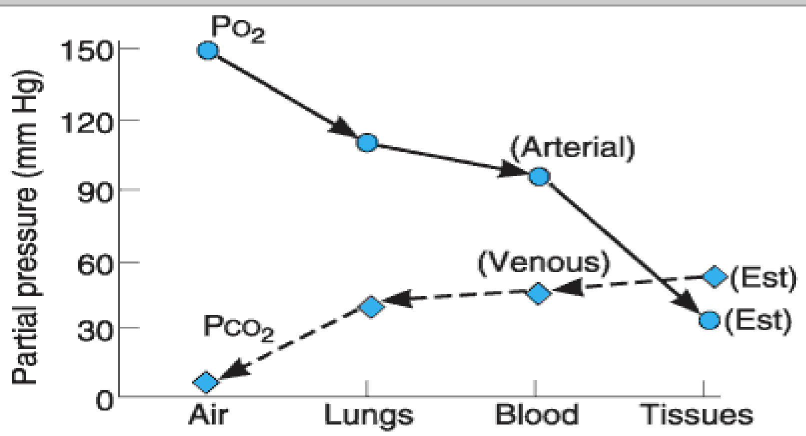
Our body don't use nitrogen but it decrease to provide space.



O2 decrease due to the normal physiological shunt: the arterial blood mix with venous blood which come from bronchial tree and cardiac muscle

PO_2, PCO_2 in air, lung and tissue:

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.)

PO_2, PCO_2 in various portion of normal expired air:

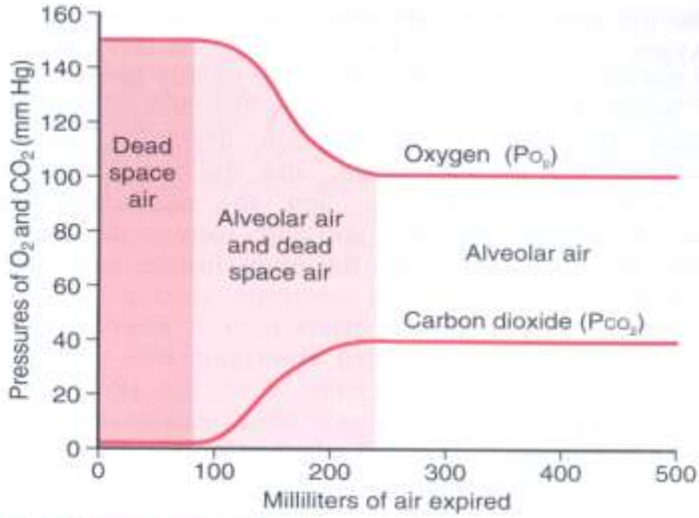


FIGURE 39–6

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

- At resting condition 250ml of oxygen enter the pulmonary capillaries/min at ventilatory rate of 4.2 L/min.or 4200ml/min.

- During exercise is absorbed by the pulmonary capillaries per 1000 ml of oxygen minute, the rate of alveolar ventilation must increase four times to maintain the alveolar PO2 at the normal value of 104 mmHg.

> During rest we enter 4200ml air per minute O2 represent 250 ml from the total volume (4200ml)and during exercise it decrease to 1000 so the normal volume during rest increase four times (250 *4)also the total volume increase four times (4200*4)

- Normal rate of carbon dioxide excretion is 200ml/min, at normal rate of alveolar ventilation of 4.2L/min.

GOOD LUCK