Diffusion of Oxygen & Carbon Dioxide

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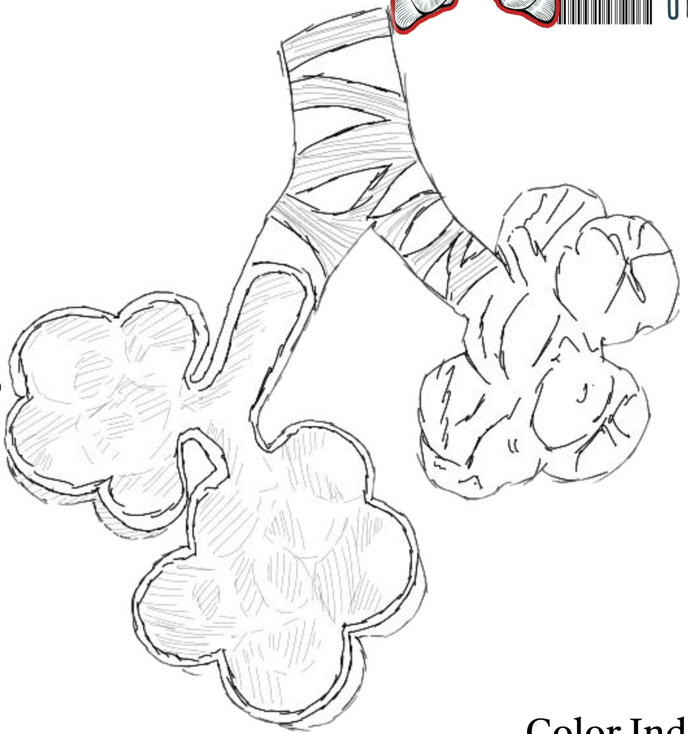

Color Index:
-Main Text -Important -Notes
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Special Thanks to Hasan Alsughayir for the Sketch <3

Male Dr: Thamir Al-khlaiwi
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Objectives

01 Define partial pressure of a gas.

02 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).

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

04 Understand that gases in a liquid diffuse from higher partial pressure to lower partial pressure (Henry's Law).

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

06 Identify the various factors determining gas transfer: surface area, thickness, partial pressure difference, and diffusion coefficient of gas.

07 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.

Partial Pressures & Solubilities

Thickness & Surface Area of Respiratory Membrane

REVIEW Gas Exchange From Guyton

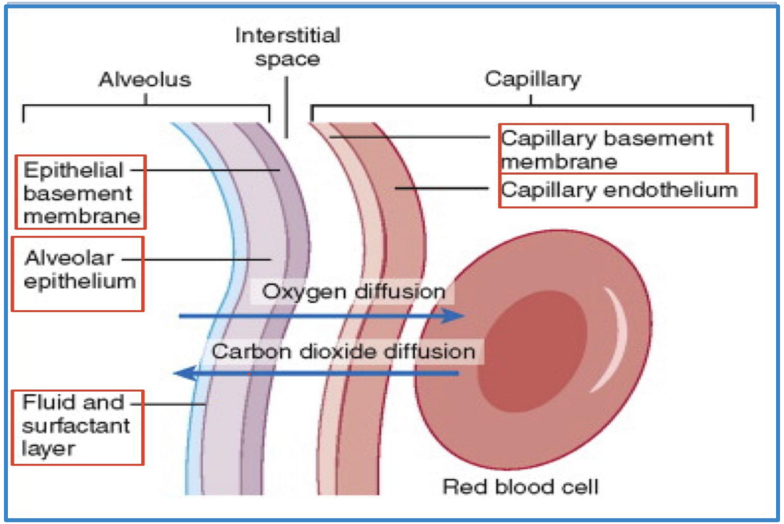
Respiratory Membrane Layers (From Inside to Outside)

1 A layer of fluid containing surfactant that lines alveolus & reduces surface tension of alveolar fluid.

2 Alveolar epithelium, which is composed of thin epithelial cells.

3 An epithelial basement membrane.

Male Slides Only



شرح لطريقة عبور الـ O2 وطريقة عبور الـ CO2 عكسها

4 A thin interstitial space (يتغير حجمه حسب الظروف) between alveolar epithelium & capillary membrane.

5 A capillary basement membrane that in many places fuses with alveolar epithelial basement membrane.

6 The capillary endothelial membrane.

Gas Exchange through Respiratory Membrane

- After ventilation of alveoli with fresh air → diffusion of O_2 & co_2 across respiratory membrane (alveolo-capillary membrane).

There is no gas exchange in terminal bronchi

- **Thickness:** 0.2 - 0.6 micrometer.
- **Total surface area:** 50 - 100 m^2 in a normal adult human male, or 70 m^2.

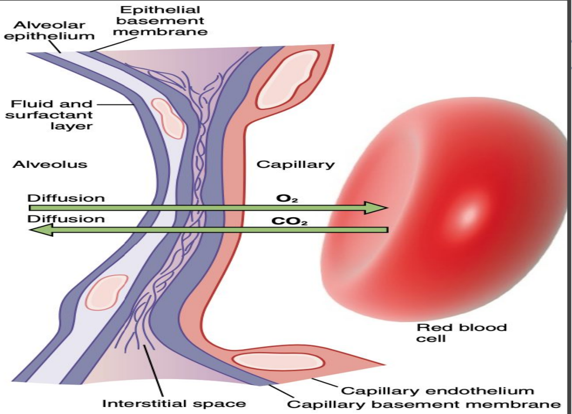


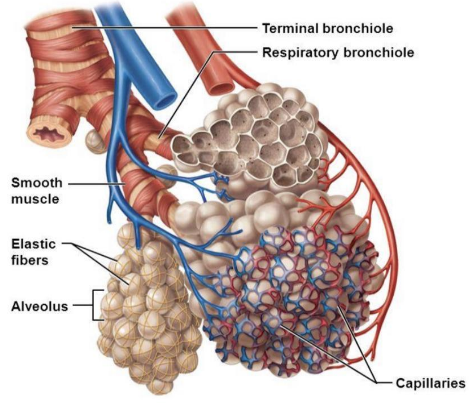
Figure 39-9 Ultrastructure of the alveolar respiratory membrane shown in cross section.

> Doctor said:
> Gas exchange criteria:
> -Wide space
> - Thin membrane

- Total quantity of blood in lungs' capillaries at any given instant: 60 - 140 ml.

- This small amount of blood spread over the entire surface of a 25 × 30-foot floor → it is easy to understand the rapidity of the respiratory exchange of O_2 & CO_2.

Figure 22.9a Alveoli and the respiratory membrane.



(a) Diagrammatic view of capillary-alveoli relationships

Partial Pressure of Gases

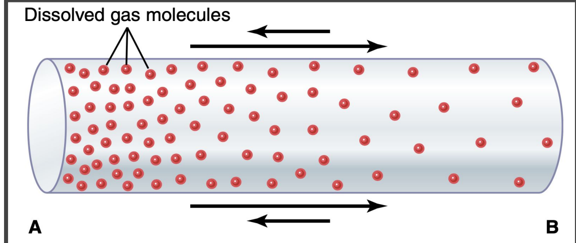
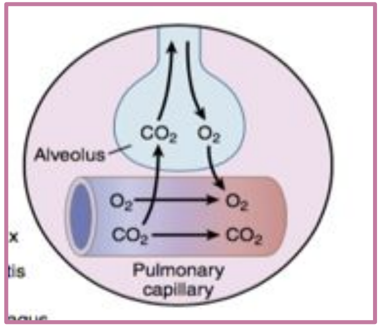


Figure 39-1 Diffusion of oxygen from one end of a chamber (*A*) to the other (*B*). The difference between the lengths of the arrows represents *net diffusion*.

- Gases of physiological importance are: O_2 & CO_2.
- Rate of diffusion of each of these gases is directly proportional to the partial pressure of this gas alone, which is called the partial pressure of the gas.
- Pressure is caused by: constant impact of kinetically moving molecules against a surface.
- Pressure of a gas acting on surfaces of respiratory passages & alveoli is proportional to the summated force of impact of all molecules of that gas striking the surface at any time.
  - Pressure of a gas is directly proportional to the concentration of gas molecules.



🩺 Doctor said:
"Concentration is the moving force but we're gonna call it partial pressure"

Thanks to 39 team!

Explanation of Partial pressure of gases (in a mixture)

From Guyton

The concept of partial pressure can be explained **as follows:**
Consider air, which has an approximate composition of 79% nitrogen and 21% oxygen. The total pressure of this mixture at sea level averages 760 mmHg. 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% of the 760 mmHg is caused by nitrogen (600 mmHg) and 21% by O_2 (160 mm Hg).
- ➔ Thus, the “partial pressure” of nitrogen in the mixture is 600 mmHg, and the “partial pressure” of O_2 is 160 mmHg; 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 PO_2, PCO_2, PN_2, and so forth.

Diffusion of Gases Between the Gas Phase in Alveoli and Blood

The partial pressure of each gas in the alveolar respiratory gas mixture tends to force molecules of that gas into solution in the blood of the alveolar capillaries. Conversely, the molecules of the same gas that are already dissolved in the blood are bouncing randomly in the fluid of the blood, and some of these bouncing molecules escape back into the alveoli. The rate at which they escape is directly proportional to their partial pressure in the blood.

But in which direction will net diffusion of the gas occur?
The answer is that net diffusion is determined by the difference between the two partial pressures. If the partial pressure is greater in the gas phase in the alveoli, as is normally true for oxygen, then more molecules will diffuse into the blood than in the other direction. Alternatively, if the partial pressure of the gas is greater in the dissolved state in the blood, which is normally true for CO_2, then net diffusion will occur toward the gas phase in the alveoli.

Dalton's Law of Partial Pressures

Dalton's Law of Partial Pressures: the partial pressure of a gas in a mixture of gases is the pressure that gas would exert if it occupied the total volume of the mixture.

- **Partial pressure:** total pressure multiplied by fractional concentration of dry gas.

  For humidified gas: $PX = (PB - PH_2O) \times F$

Dalton's Law

$PX = PB \times F$

- PX = partial pressure of gas (mmHg)
- PB = barometric pressure (760 mmHg)
- PH_2O = water vapor pressure at 37°C (47 mmHg)
- F = fractional concentration of gas (0.21 no unit)

Barometric pressure (PB): the sum of partial pressures of O_2, CO_2, N_2, & H_2O.

- Percentages of gases in dry air at a barometric pressure of 760 mmHg:
  - O_2 = 21% (0.21)
  - N_2 = 79% (0.79)
  - CO_2 = 0% (0)
- Air is humidified in airways → water vapor pressure (47 mmHg at 37°C) is obligatory.

Partial Pressures of O_2 & CO_2

O_2 concentration in atmosphere: 21%

PO_2 in atmosphere:

= 760 mmHg x 21%

= 160 mmHg

Mixes with "old" air already present in alveoli → PO_2 becomes 104 mmHg in alveoli.

CO_2 concentration in atmosphere: 0.04%

PCO_2 in **atmosphere:**

= 760 mmHg x 0.04%

= 0.3 mmHg

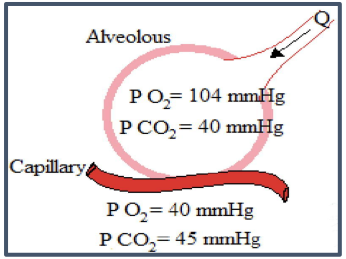
Mixes with high CO_2 levels from residual volume in the alveoli → PCO_2 becomes 40 mmHg in alveoli.

Partial Pressure of O_2

In atmosphere → 760 x 0.21 = 160 mm Hg

Conductive zone → (760-47) x 0.21 = 150 mm Hg

Net diffusion



Humidification of air in respiratory passages

- Atmospheric air: nitrogen + O_2 + almost no CO_2 & little water vapor.
- As soon as atmospheric air enters respiratory passages, it is exposed to fluids that cover respiratory surfaces.
- Even before air enters alveoli: it becomes almost totally humidified.

"Respiratory zone"

- 🩺 Doctor said:
  Nitrogen doesn't diffuse to blood (Normally)

Table 40-1 Partial Pressures (in mm Hg) and composition (in percentages) of Respiratory Gases as They Enter and Leave the Lungs[a]

	Atmo-spheric Air	Humidi-fied Air	Alveolar Air	Expired Air
N_2	597 (78.62)	563.4 (74.09)	569 (74.9)	566 (74.5)
O_2	159 (20.84)	149.3 (19.67)	104 (13.6)	120 (15.7)
CO_2	0.3 (0.04)	0.3 (0.04)	40 (5.3)	27 (3.6)
H_2O	3.7 (0.50)	47 (6.20)	47 (6.2)	47 (6.2)
Total	760 (100)	760 (100)	760 (100)	760 (100)

[a]At sea level.

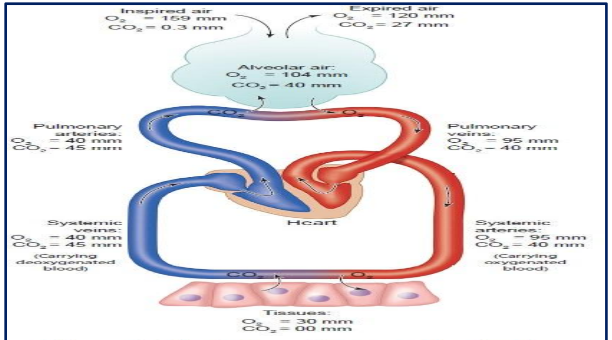


Figure 6.6 Exchange of gases at the alveolus and the tissue with blood and transport of oxygen and carbondioxide

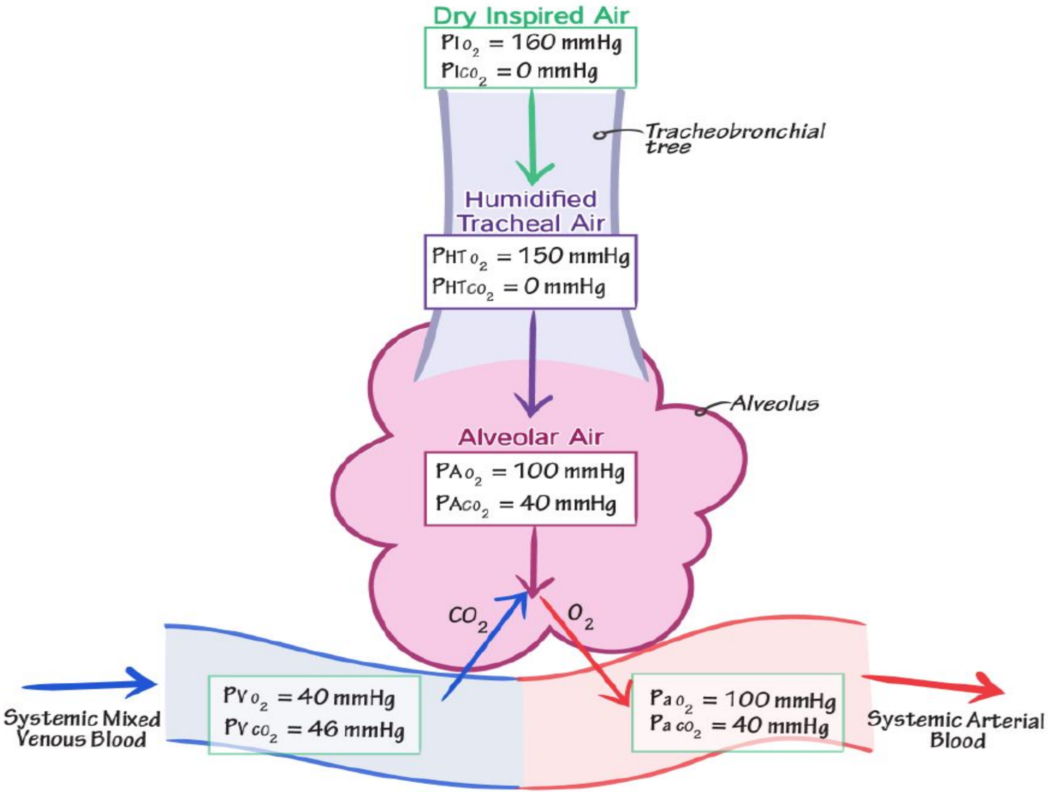
Values for PO_2 & PCO_2 in inspired dry, humidified tracheal, alveolar air, & pulmonary blood.

Thanks to 443 team!

EXTRA

Partial Pressures of O_2 & CO_2

Important Slide



Partial Pressures of respiratory gases as they enter and leave the lungs (at sea level)

Male Slides Only

(mmHg)	NH2	O2	CO2	H2O
Atmospheric air	597.0(78.62%)	159.0(20.84%)	0.3(0.04%)	3.7(0.50%)
Humidified air	563.4(74.09%)	149.3(19.67%)	0.3(0.04%)	47.0(6.20%)
Alveolar air	569.0(74.9%)	104.0(13.6%)	40.0(5.3%)	47.0(6.2%)
Expired air	566.0(74.5%)	120.0(15.7%)	27.0(3.6%)	47.0(6.2%)

Factors Affecting Gas Diffusion

Fick's Law/Principle

$$D \text{ (diffusion) } \alpha \; \frac{\Delta P \times A \times S}{d \times \sqrt{MW}}$$

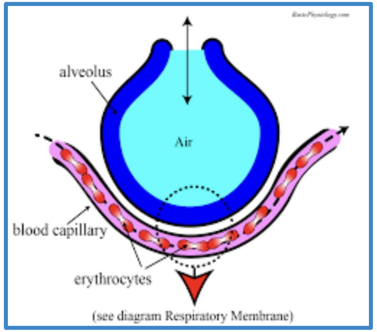
A:
Surface area for gas exchange.
Total surface area of respiratory membrane 50 - 100 m2 in normal adult

S:
Solubility of gas in the body fluids.

ΔP:
Partial pressure differences.

MW:
Molecular weight of gas.

d:
Diffusion distance
Thickness of respiratory membrane



Fluid Temperature:
Body's temperature remains reasonably constant → usually not considered.

Diffusion Coefficient of Gas (D) =

$$\frac{S}{\sqrt{MW}}$$

Factors Affecting Gas Diffusion

MW of O_2 < MW CO_2 ; CO_2 is 24 times more soluble than O_2.

→ Net result: CO_2 diffusion ~20 times faster than O_2 diffusion.

Factors determining the partial pressure of a gas dissolved in a solution:

→ Gas concentration → Solubility coefficient of the gas

Henry's Law

$$\text{Partial Pressure} = \frac{\text{Concentration of dissolved gas}}{\text{Solubility coefficient}}$$

Partial pressure of CO_2 (for a given conc.) is less than one twentieth (5%) that exerted by O_2.

Relative rates at which different gases at the same pressure level will diffuse are proportional to their diffusion coefficient:

→ O_2 = 1.0 → CO_2 = 20.0 → N_2 = 0.53

Doctor said:
Alveoli has a spherical shape → more surface area → more diffusion occurs.

Alveolar Air & Atmospheric Air Composition

Alveolar and atmospheric air concentrations of gases are different due to 4 reasons :

01 Alveolar air is only partially replaced by atmospheric air with each breath.

- Only 350 ml of new air is brought into alveoli with each normal inspiration, and the same amount of old alveolar air is expired.

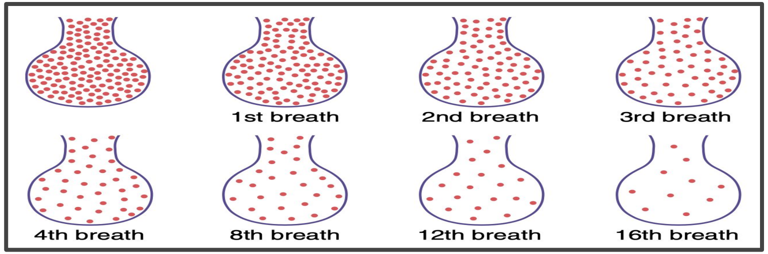
i.e. Volume of alveolar air replaced by new atmospheric air with each breath is only one seventh of total.

02 Oxygen is being absorbed into the pulmonary blood from alveolar air.

03 Carbon dioxide is diffusing from the pulmonary blood into the alveoli.

04 Dry atmospheric air is humidified even before it reaches the alveoli.

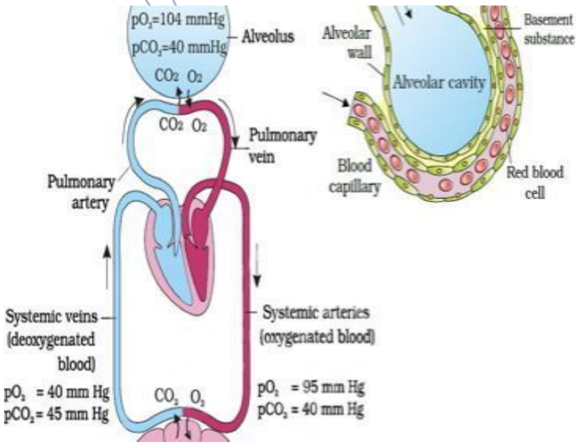
	Inspired air	Alveolar air
H_2O	Variable	47 mmHg
CO_2	000.3 mmHg	40 mmHg
O_2	159 mmHg	105 mmHg
N_2	601 mmHg	568 mmHg
Total pressure	760 mmHg	760 mmHg



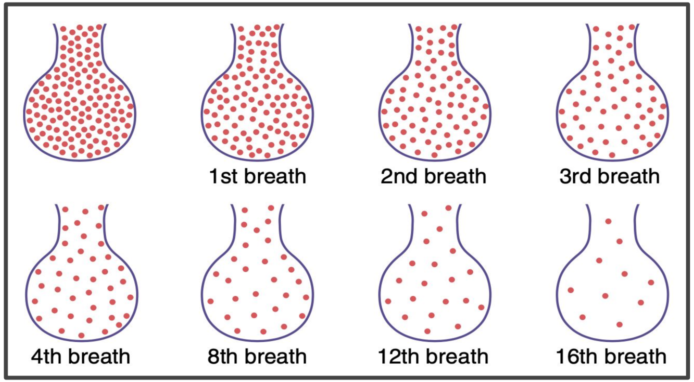
Exchange of gas from an alveolus with successive breaths.

Slow Replacement of Alveolar Air

Importance of the slow replacement of alveolar air:



- Prevent sudden changes in gas concentrations in blood
- Makes the respiratory control mechanism much more stable
- Helps preventing excessive increases & decreases in:
  - Tissue oxygenation
  - Tissue CO_2 concentration
  - Tissue PH when respiration is temporarily interrupted



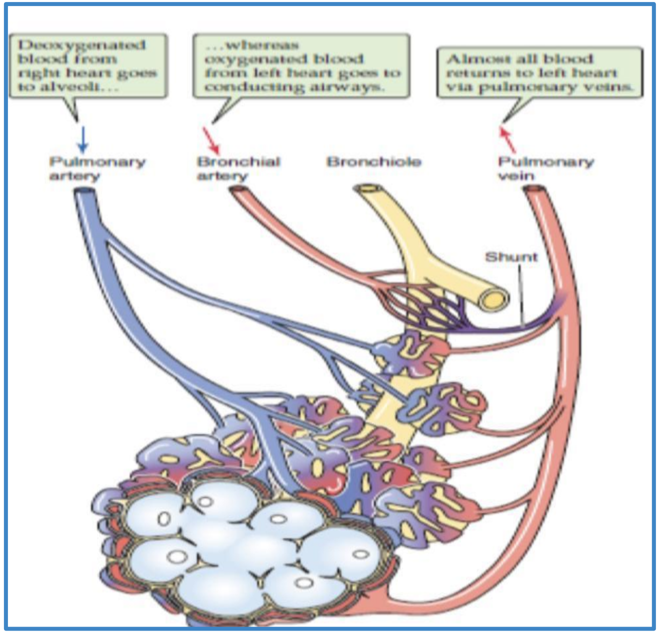
From Guyton
Air is expired. Therefore, the volume of alveolar replaced by new atmospheric air with each breath only one seventh of the total ,so multiple breaths required to exchange most of alveolar air.this figure shows this slow rate of renewal of the alveolar air.in the first alveolus of the figure , excess gas is present in the alveoli but note that even at the end of 16 breaths the excess gas still has not been completely removed from alveoli

🩺 Doctor said:
PO_2 goes down as it moves from atmosphere to alveoli.
PCO_2 goes up as it moves from alveoli to atmosphere.

Male Slides Only

Transport of O_2 in Arterial Blood

- **About 98% of blood:** Lungs → alveolar capillaries (oxygenated up to PO_2 = 104 mmHg) → left atrium.
- **About 2% of blood (shunt flow):**
  Left atrium → left ventricle → aorta → bronchial circulation (supplies deep tissues of lungs + not exposed to lung air) → lungs (PO_2 = pressure of normal systemic venous blood = 40 mmHg).
  Blood is shunted & bypass the gas exchange areas.
- **PO_2 of shunt blood:** PO_2 of shunt blood after leaving lungs = normal systemic venous blood = 40 mmHg.
- **Venous Admixture In pulmonary veins:** shunted blood combine with oxygenated blood from alveolar capillaries (**venous admixture** of blood) → PO_2 of blood entering left heart into the aorta to falls to 95 mmHg.



Pulmonary Shunt

The Dr. focused on the site of the shunt.
So, where does the shunt appears? Bronchial veins

PO_2 & PCO_2 in Normal Expired Air

Normal expired air contains: dead space air + alveolar air.

Normal expired air has gas concentrations & partial pressures that is between those of alveolar air and humidified atmospheric air.

🩺 Doctor said:

Conduction zone: dead space air

- PO_2 decreases as it enters conduction zone (160 → 149)
- PCO_2 does not change

Respiratory zone: normal expired air + alveolar air

- PO_2 begins to decrease (149 → 104)
- PCO_2 begins to increase (~0 → 40) from capillaries.

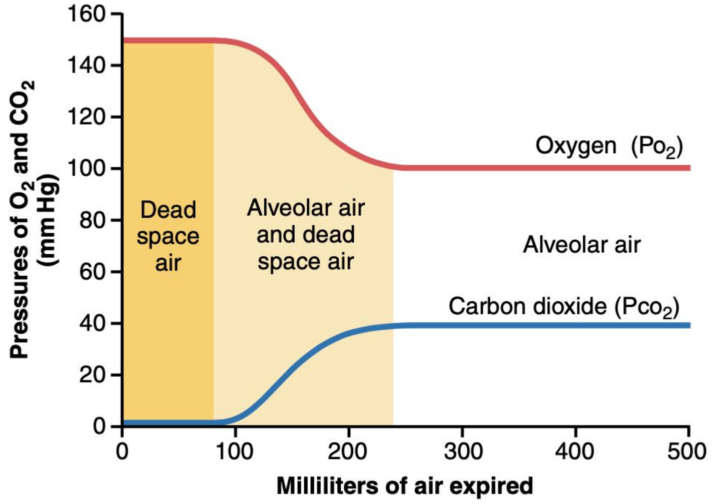


Figure 39-6 Oxygen and carbon dioxide partial pressures in the various portions of normal expired air.

Diffusion of O_2

01 Alveoli → Pulmonary capillaries

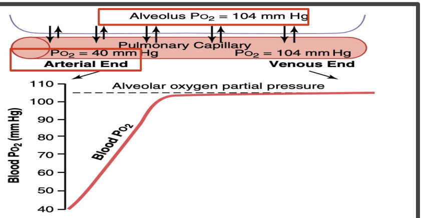


Figure 40-1 Uptake of oxygen by the pulmonary capillary blood. (The curve in this figure was constructed from data in Milhorn HT Jr, Pulley PE Jr: A theoretical study of pulmonary capillary gas exchange and venous admixture. Biophys J 8:337, 1968.)

439:
1-All arteries in the body are oxygenated except pulmonary artery.
2-All veins in the body are deoxygenated except the pulmonary vein.

02 Systemic capillaries → Tissues

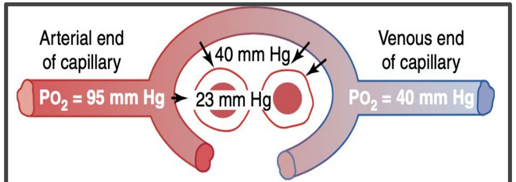


Figure 40-3 Diffusion of oxygen from a peripheral tissue capillary to the cells. (Po_2 in interstitial fluid = 40 mm Hg, and in tissue cells = 23 mm Hg.)

🩺 Doctor said:

Pulmonary shunt:
As the blood in the pulmonary vein is transported to the left atrium in order to be pumped to the systemic tissues PO_2 changes 104 → 95 as this blood is mixed with some blood from the bronchial tree veins to nourish the lung tissue itself (the only venous blood in left atrium).

Diffusion of CO_2

01 Peripheral tissue cells → Capillaries

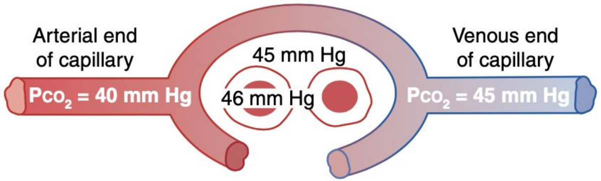


Figure 40-5 Uptake of carbon dioxide by the blood in the tissue capillaries. (Pco_2 in tissue cells = 46 mm Hg, and in interstitial fluid = 45 mm Hg.)

02 Pulmonary capillaries → Alveoli

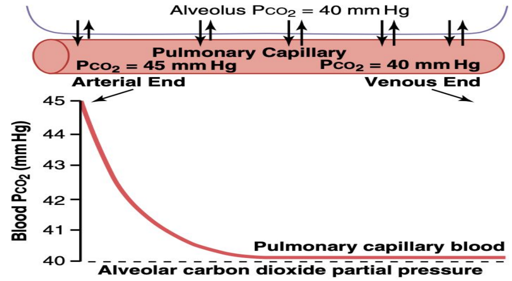


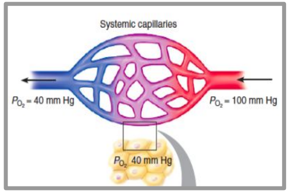
Figure 40-6 Diffusion of carbon dioxide from the pulmonary blood into the alveolus. (This curve was constructed from data in Milhorn HT Jr, Pulley PE Jr: A theoretical study of pulmonary capillary gas exchange and venous admixture. Biophys J 8:337, 1968.)

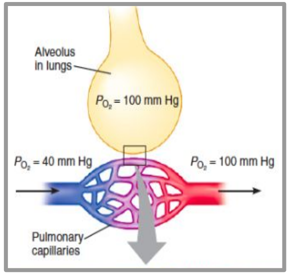
Thanks to 443 team!

EXTRA

Diffusion of Oxygen & CO2

Oxygen



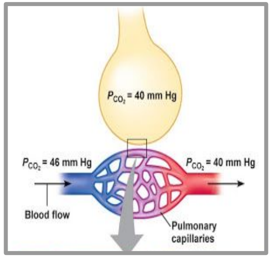


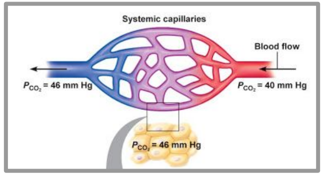
الـPO_2 بالدم بداية (arterial end) رح يكون 40 mmHg لكن بما ان ضغط الـO_2 في الـalveoli (104 mmHg) أكبر من الدم (40) رح يبدأ الـO_2 بالـ diffuse للـcapillaries ومع استمرار الـ diffusion بيوقف لما نوصل الـequilibrium وبكذا ينتهي الـPO_2 في الدم بالأرتفاع (104 mmHg) فيما نطلق عليه الـvenous end.

طيب الحين الدم طلع من الرئة محمل بالأكسجين و الضغط 104، كيف وصل للخلايا بالصورة اليمين وهو 95؟ دخل عليه دم غير مؤكسج و هو بطريقه للقلب والـaorta ونتج عن ذلك انخفاض الضغط من 104 إلى 95.

بيبدا الـO_2 بالـdiffusion من الدم إلى الـ interstitial fluid (40 mmHg) إلى الخلايا (23 mmHg) ويطلع الدم مره ثانية 40 mmHg للقلب ومنه للرئة.

Carbon Dioxide





الخلايا أخذت الأكسجين اللي تكلمنا عنه تو الحين رح تعطي الدم الـCO_2 بما ان الـPCO_2 في الـ interstitial fluid (45 mmHg) أقل من الخلايا (46 mmHg) رح ينتقل الـ CO_2 إلى الـ interstitial fluid وبما أن الـPCO_2 بالدم (40 mmHg) أقل من الـ interstitial fluid رح ينتقل الـCO_2 إلى الدم (vein).

الـvein بيحمل الـCO_2 للجزء الأيمن من القلب اللي بدوره بيضخ الدم للرئة عبر الـpulmonary artery.

الـPCO_2 بالدم بداية (arterial end) رح يكون 45 mmHg لكن بما ان ضغط الـCO_2 في الـalveoli (40 mmHg) أقل من الدم (45) رح يبدأ الـCO_2 بالـ diffuse للـalveoli ومع استمرار الـ diffusion بيوقف لما نوصل الـequilibrium وبكذا ينتهي الـPCO_2 في الدم بالإنخفاض (40 mmHg) فيما نطلق عليه الـvenous end وبيرتفع بالـalveoli اللي رح تتخلص منه بالـexpiration.

O_2 Concentration in Alveoli

At resting conditions:

- 250 ml of O2 are extracted by tissues at Ventilation rate of 4.2 L/min.

During exercise:

- 1000 ml of O2 is extracted by tissues per minute.
- Rate of alveolar ventilation must increase 4 times to maintain the alveolar PO2 at normal value (104 mmHg).

O2 concentration in alveoli & O2 partial pressure are controlled by:

- Rate of absorption of O2 into blood.
- Rate of entry of new O2 into lungs by the ventilatory process.

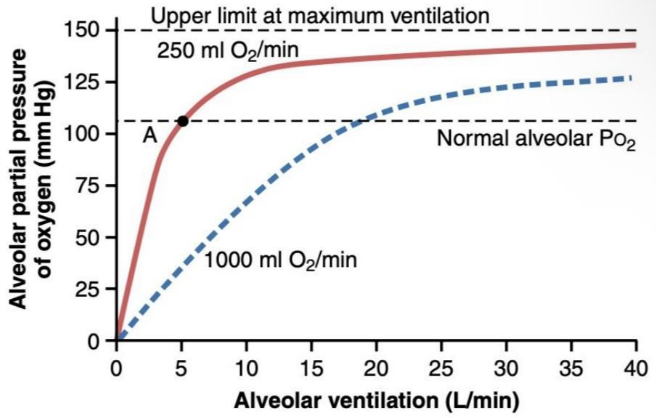


Figure 39-4 Effect of alveolar ventilation on the alveolar Po_2 at two rates of oxygen absorption from the alveoli—250 ml/min and 1000 ml/min. *Point A* is the normal operating point.

Female Slides Only

Effect of alveolar ventilation on alveolar PCO2

Normal rate of CO2 excretion: 200 ml/min, at normal rate of alveolar Ventilation rate of 4.2 L/min.

Alveolar PCO2 increases directly in proportion to the rate of CO2 excretion by tissues.

Alveolar PCO2 decreases in inverse proportion to alveolar ventilation.

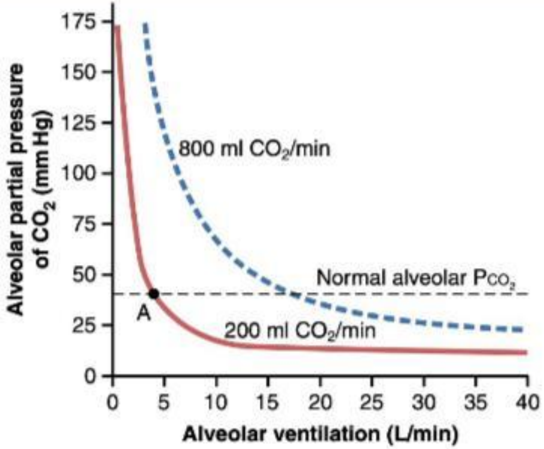


Figure 39-5 Effect of alveolar ventilation on the alveolar P_{CO_2} at two rates of carbon dioxide excretion from the blood—800 ml/min and 200 ml/min. *Point A* is the normal operating point.

Female Slides Only

Summary

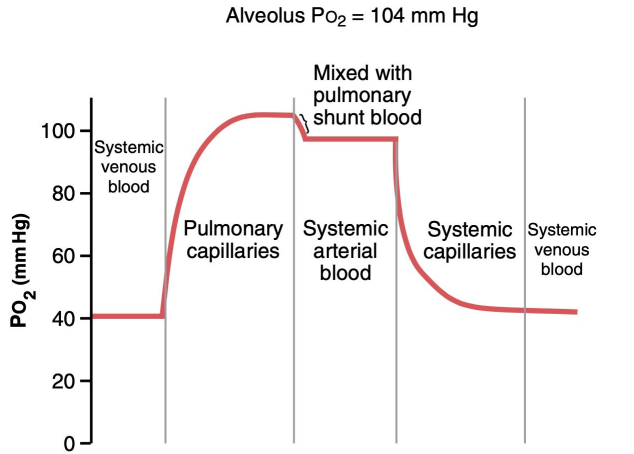
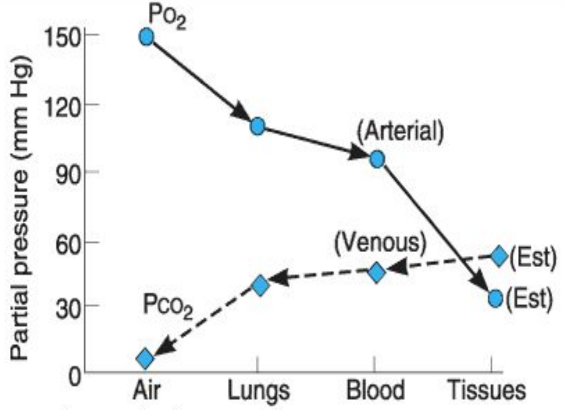


Figure 40-2 Changes in Po_2 in the pulmonary capillary blood, systemic arterial blood, and systemic capillary blood, demonstrating the effect of "venous admixture."

Changes in PO2 in pulmonary capillary, systemic arterial, and systemic capillary blood demonstrating the effect of venous admixture.



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 air, lung and tissues.

MCQs

Q1: A cardiac catheterization is performed in a healthy adult. The blood sample withdrawn from the catheter shows 95mmHg of O2 saturation. Where was the catheter tip located?			
A- alveolar capillaries	B- Left heart	C- systemic venous blood	D- Pulmonary artery
Q2: If alveolar surface area is decreased 50% and pulmonary edema leads to a doubling of diffusion distance, how does diffusion of O2 compare with normal?			
A- 25% increase	B- 25% decrease	C- 50% decrease	D- 75% decrease
Q3: Why is CO2 more permeable than O2 ?			
A- Higher MW	B- Higher partial pressure	C- Higher solubility	D- All of the above

1-B 2-D 3-C

MCQs

Q4:Which of the following describes diffusing capacity of O2 in the lung?			
A-Doesn't change during exercise	B- Is greater than diffusing capacity for CO2	C-the Po2 of it is 760mmHg	D- Is directly related to alveolar capillary surface area

4-D

SAQs

Q1: Mention 4 of factors affecting gas diffusion?

Q2: Lung air is not replacement quickly but slowly, what is the importance of that?

Q3: why is alveolar and atmospheric air concentrations of gases are different? mention 3 reasons

Q4: Describe in briefly the

process of O2 Diffusion?

A1:
ΔP: Partial pressure
A: Surface area
S: Solubility
MW
d: Diffusion distance.

A2: slide 16

A3: slide 15

A4: slide 19

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