Respiratory Gases Exchange

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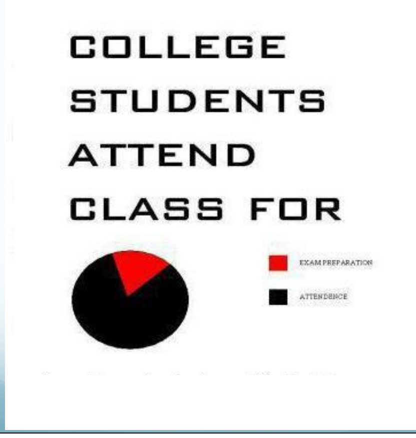
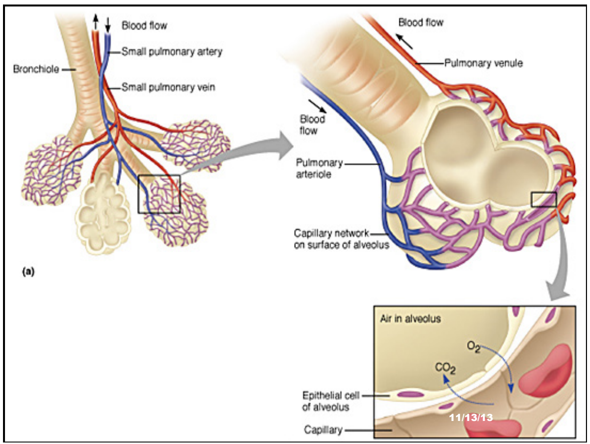
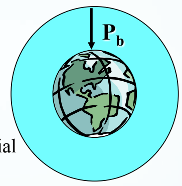




I Physical Principles of Gas Exchange

- Partial pressure
  - The pressure exerted by each type of gas in a mixture
- Diffusion of gases through liquids
  - Concentration of a gas in a liquid is determined by its **partial pressure** and its **solubility**

Partial Pressures of Gases



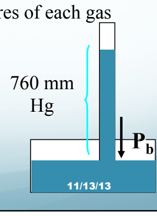
Basic Composition of Air
- 79% Nitrogen
- 21 % Oxygen
- ~ 0% Carbon Dioxide

In a mixture of gases, each gas exerts a partial pressure proportional to its mole fraction

Total Pressure = sum of the partial pressures of each gas

Total Pressure (at sea level)

$P_{barometric}$ = 760 mm Hg



$P_{gas} = P_b \times F_{gas}$

$P_N = 760 \times 0.79 = 600.4$ mm Hg

$P_{O_2} = 760 \times 0.21 = 159.6$ mm Hg

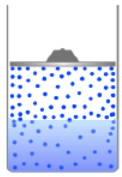
THE PARITAL PRESSURE OF OXYGEN DECREASES AS INSPIRED AIR COURSES THROUGH THE AIRWAYS

PO_2 = 160 mmHg PCO_2 = 0 P_{H2O} = 0		DRY AIR AT SEA LEVEL
PO_2 = PCO_2 = P_{H2O} =	150 0 47	CONDUCTING AIRWAYS (HEATED & HUMIDIFIED)
PO_2 = PCO_2 = P_{H2O} =	100 40 47	ALVEOLI (MIXED IN A RESERVOIR OF AIR--FRC)

PARTIAL PRESSURE OF GASES DISSOLVED IN SOLUTION

At equilibrium, the tension of gas in solution = the partial pressure of gas in the pocket above it.

- Gases flow from a region of higher partial pressure to one of lower pressure.
- Gases dissolve, diffuse, and react according to their partial pressures and not according to their concentration in solution



note that the concentration of gas in solution is not the same as its partial pressure as solubility of gas affects its concentration

Ficks Law

- Amount of gas passing through a membrane is directly proportional to the area of the membrane, diffusivity of the gas and pressure deference
- but inversely prpertional to thickness of the membrane

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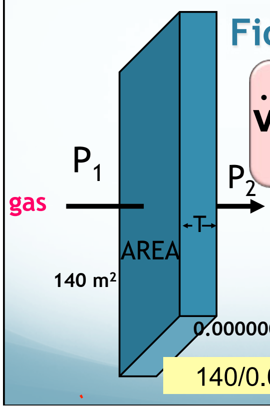
Fick's Law



flux

$$\dot{V}_{gas} = \frac{A}{T} \times K \times (P_1 - P_2)$$

$$K = \frac{Sol.}{\sqrt{Mol.\ Wt.}}$$

140/0.0000005 = 280,000,000

- diffusion dependent on perfusion and the partial pressure (pp) exerted by each gas
- gases diffuse from area of ↑ conc. (pp) to ↓ conc. (pp)

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Diffusion

- ↑concentration ↑ → ↑pp of gas → ↑diffusion
- CO_2 more soluble than O_2, therefore it diffuses faster

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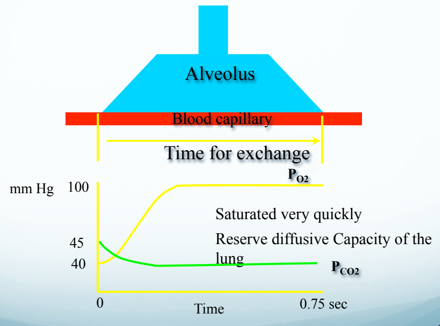
Diffusion: Blood Transit time in the Alveolus



II Gas exchange in the lung and in the tissue

Oxygen and Carbon Dioxide Diffusion Gradients

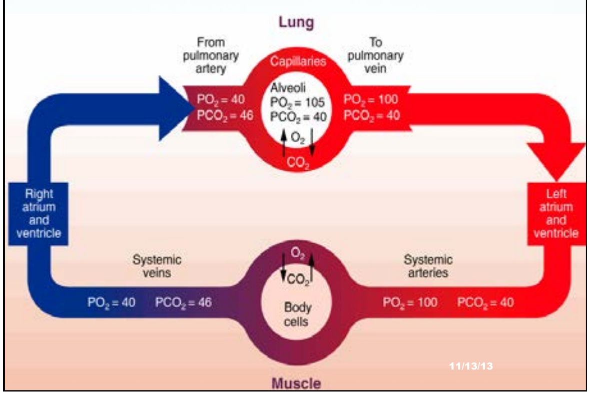
- Oxygen
  - Moves from alveoli into blood.
    - Blood is almost completely saturated with oxygen when it leaves the capillary
    - $P0_2$ in blood decreases because of mixing with deoxygenated blood
    - Oxygen moves from tissue capillaries into the tissues
- Carbon dioxide
  - Moves from tissues into tissue capillaries
  - Moves from pulmonary capillaries into the alveoli

Diffusion Gradients of Respiratory Gases at Sea Level

Gas	% in dry air	Partial pressure (mmHg) Dry air	Alveolar air	Venous blood	Diffusion gradient
Total	100.00	760.0	760	760	0
H_2O	0.00	0.0	47	47	0
O_2	20.93	159.1	105	40	65
CO_2	0.03	0.2	40	46	6
N_2	79.04	600.7	569	573	0

NB. *CO_2 is ~20x more soluble than O_2 in blood => large amounts move into & out of the blood down a relatively small diffusion gradient.*

PO_2 and PCO_2 in Blood

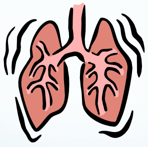


III. A-a gradient, the efficiency of the gas exchange in alveoli

What is an A - a gradient ?

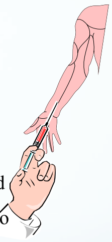
The **DIFFERENCE** between

Oxygen Content in Alveolus Gas (measured during exhalation)



Oxygen Content in arterial blood

(equivalent to that leaving lungs)



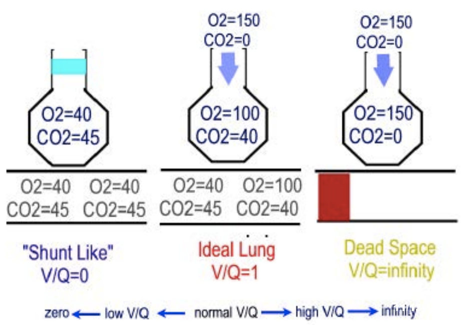
In a healthy person, what would you expect the A - a to be?
No difference, greater than 0, or less than 0

Normal: A – a, up to ~ 10 mm Hg, varies with age

Factors contributing to A - a Gradient

1. Blood Shunts
2. Matching

VENTILATION PERFUSION MISMATCH AFFECTS ARTERIAL BLOOD GAS VALUES



IV Factors Affecting the Gas Diffusion in the Lung

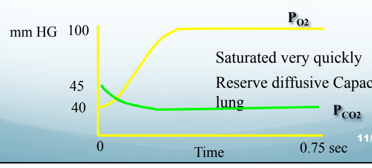
1. The Properties of the Gas

1) Molecular weight. Diffusion rate is inversely proportional to the square root of the molecular weight
2) Temperature
3) Solubility in water

Each gas has a specific solubility

O_2 Solubility coefficient = 0.003 ml 0_2/100 ml Blood

$C0_2$ = 0.06 ml/100 ml Blood (x 20 of 0_2)



2. Partial Pressure of the Gases

1) Alveoli ventilation
2) Blood perfusion in the lung capillary
3) Speed of the chemical reaction

The slow speed of the chemical reaction $HCO_3^- + H^+$ ----- H_2CO_3 ---$H_2O + CO_2$ reduces the CO_2 exchange in the lung.

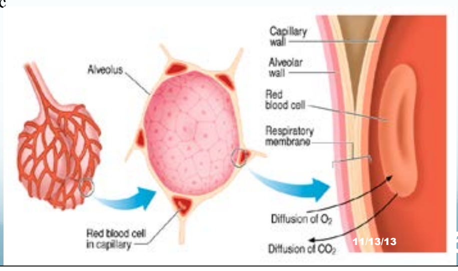
So, during the gas exchange in the external respiration, the exchange of CO_2 is a little lower than that of O_2.

3. Properties of the Lung

1) Area of the respiratory membrane

2) Distance of the diffusion

3) V_A/Q_c



V Pulmonary Diffusion Capacity

Concept:

The ability of the respiratory membrane to exchange a gas between the alveoli and the pulmonary blood

defined as the volume of a gas that diffuses through the membrane each minute for a pressure of 1 mmHg.

$D_L = V/(P_A - P_C)$

V is a gas that diffuses through the membrane each minute,

P_A is the average partial pressure of a gas in the air of alveoli,

P_C is the average partial pressure of a gas in the blood of pulmonary capillary.

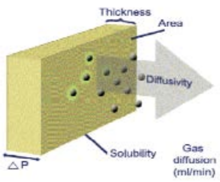
Factors Affecting the D_L

1. Body posture
2. Body height and weight
3. Exercise
4. Pulmonary diseases

VI Factors Affecting the Gas Exchange

FACTORS THAT AFFECT DIFFUSION OF GASES ACROSS BARRIERS

Fick's Law Of Diffusion



$\dot{V}_{GAS} \propto \frac{A\ D\ [\Delta P]}{T}$

D = "DIFFUSIVITY" or "DIFFUSION COEFFICIENT" $\propto$ SOLUBILITY/ $\sqrt{MW}$

Compare D & ΔP of O_2 and CO_2 and explain equal time for end capillary equilibration of these gases in the lungs.

EFFECT OF SURFACE AREA ON GAS EXCHANGE

Loss of Surface Area

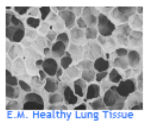
EMPHYSEMA

⬇

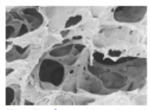
DESTRUCTION OF ALVEOLAR WALLS

⬇

↑LUNG COMPLIANCE
MECHANICAL COMPLICATION
&
AREA FOR GAS EXCHANGE
↓GAS EXCHANGE COMPLICATION



E.M. Healthy Lung Tissue



E.M. Emphysematous Lungs

Other

- Athelectasis (Collapse Of Lung Parenchyma)
- Surgical Removal Of Lung Tissue

EFFECT OF THICKNESS ON GAS EXCHANGE

Increased Thickness

PULMONARY FIBROSIS (scar formation) results in response to exposure to--

- industrial dust [asbestosis, silicosis]
- spores from moldy hay [Farmers lungs]
- antigens in avian feather/excreta [Bird breeders lung]
- therapeutic drugs, radiation, poisons [weed killer, paraquat]

Diffusivity

- The membrane character is lost due to fibrosis in diseases like asbestosis, silicosis etc which affect the solubility of a gas in the membrane and their diffusivity is also affected.

The pressure gradient

- During increased ventilation/O_2 inhalation P_{A02} increases leading to increased exchange of 0_2
- Hypoventilation, high altitude-- P_{A02} decreases

Ventilation/perfusion ratio

- If perfusion remains normal and ventilation is decresed- shunt
- If perfusion is decreased or absent and ventilation is normal– dead space.
- During emphysema V/Q ration is abnormal leading to abnormal gas exchange

Shunt

- It dilutes the oxygenated blood but don't hamper the gas exchange.
- Normally some blood is shunted via bronchial vessels, is 1% of cardiac output. Some amount of blood may remain unoxygenated which have passed via under-ventilated alveoli
- Arterial PaO2 is 95 mmHg while pulmonary capillary has 100 mmHg

Reaction time

- time required for the chemical reactions to occur in blood in relation to gas exchange. Eg 02 to combine with Hb, while CO2 to evolve $HCO3^-$
- time required by the gases to move also influences the gas transfer eg O2– plasma– RBC memebrane-inside RBC and Then Hb.

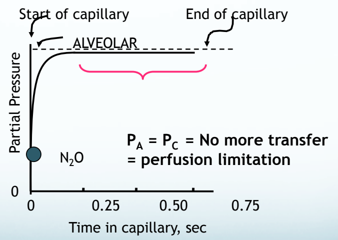
Perfusion limited transfer

- If there is more perfusion there will be more transfer is true only if gases whose partial pressure in blood rises quickly and the presure gradient is lost.
- Eg N_2O transfer will only stop unless the blood is saturated with N_2O is replaced by continuous perfusion.
- This will depend on the perfusion

Diffusion related transfer

- Its true for the gases whose partial pressure in blood doesn't rise, so the pressure gradient remains.
- CO on entering in blood combines quickly with Hb and practically no CO remains in dissolved state.
- Amount of CO Transferred depends on its rate of diffusion.

Diffusion limitation vs. perfusion limitation of gas transfer



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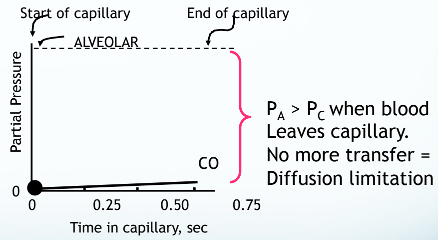
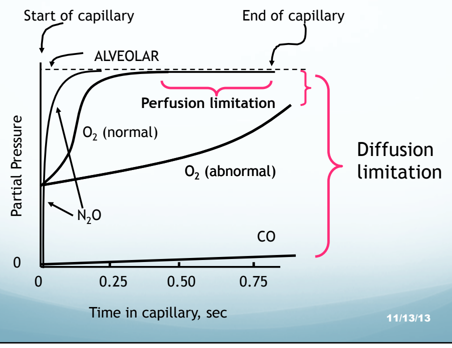


Diffusion limitation vs. perfusion limitation of gas transfer



Careers : Oral & Maxillofacial Surgery.

Thank You!

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