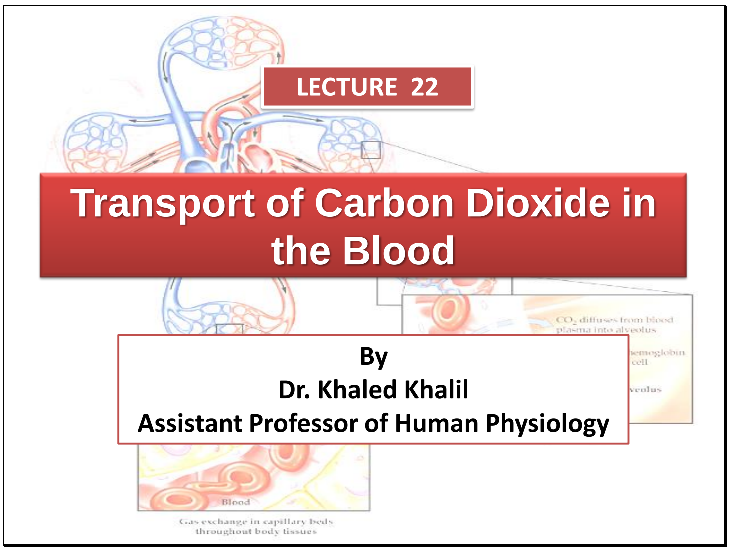
الشريحة ١

الشريحة ٢



LECTURE 22
Transport of Carbon Dioxide in the Blood
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At the end of this session, the student should be able to:

- ❑Describe the forms in which carbon dioxide is transported in the blood.
- ❑Describe the importance of the chloride shift in the transport of carbon dioxide by blood and the changes caused by this shift.
- ❑Describe carbon dioxide dissociation curves and how it is affected by oxygen binding to hemoglobin.
- ❑Discuss respiratory acidosis and alkalosis, and their compensatory role (revise).
- ❑Define respiratory exchange ratio and mention the significance of its estimation.

GUYTON & HALL Textbook of Medical Physiology, 12th edition, page: 502-504.

الشريحة ٤

Arterial CO_2

Each 100 ml of arterial blood carries 48-52 ml CO_2. This large amount is carried in two forms:

I. Physically dissolved (5%)

II. Chemical combined (95%)

- **Carbamino compounds (6%)**
- **Bicarbonate ions (89%)**

Importance of arterial CO_2:

It represent a store for strong base ($NaHCO_3$) used for **neutralization of acids** formed in the body by normal or abnormal process of metabolism. It is called **"alkali reserve"**.

Carbamino compounds (6%):

* It is the combination of CO_2 with the terminal amino group of polypeptide chains of blood proteins as Hb and plasma protein.

R - NH2 + CO2 ----------------> R – NH- COOH

* The combination occurs very rapidly without an enzyme.

Bicarbonate ions (89%):

* CO_2 combines with water to form carbonic acid. Carbonic acid being a weak acid dissociates into bicarbonate ion (HCO_3^-) and H^+ ion.

$$CO_2 + H_2O \text{ ------------> } H_2CO_3 \text{ --------> } H^+ + HCO_3^-$$

* This reaction occurs spontaneously at a slow rate but it occurs much more rapidly in the presence of **carbonic anhydrase enzyme**. Carbonic anhydrase enzyme is **present in RBCs and absent from plasma**.

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Tidal CO_2

Definition:

It is the amount of CO_2 added to 100 ml arterial blood during their passage through the tissue capillaries.

* It is about **4ml/100 ml** blood.

Carriage of tidal CO_2:

- **I. Physically dissolved** (10%)
- **II. Chemical combined** (90%)
  - **Carbamino compounds** (20%)
  - **Bicarbonate ions** (70%)

N.B.:

Reduced Hb can bind much more CO_2 than oxy HB. At the side of systemic capillaries, Hb releases oxygen, which raises its affinity for CO_2. **So, % of carbamino compounds is more in venous blood than the arterial**.

At the pulmonary capillaries, as O_2 combines to Hb, its affinity to CO_2 decreases and it releases the CO_2 that diffuses into the alveoli.

Fate of tidal CO_2:

It is transported by the venous blood to the pulmonary capillaries. Co_2 tension in the pulmonary capillaries is 46 mmHg and in the alveoli is 40 mmHg. Therefore, there is a pressure gradient of 6 mm Hg along which CO_2 crosses the alveolar membrane to the alveolar air where it is expired from the body.

Chloride Shift

At systemic capillaries:

1) When blood is exposed to high CO_2 tension (46 mmHg), Tidal CO_2 (5 ml.) is added to the blood. This excess CO_2 dissolves in water of plasma & RBCs forming H_2CO_3. Dissociation of H_2CO_3 into HCO_3^- & H^+ helps unloading of Hb and O_2 release. Thus, H^+ is trapped by Hb to form reduced hemoglobinic acid which is a weaker acid the oxyhemoglobinic acid.

$H^+ + HbO_2$ ------------------> $H.Hb + O_2$

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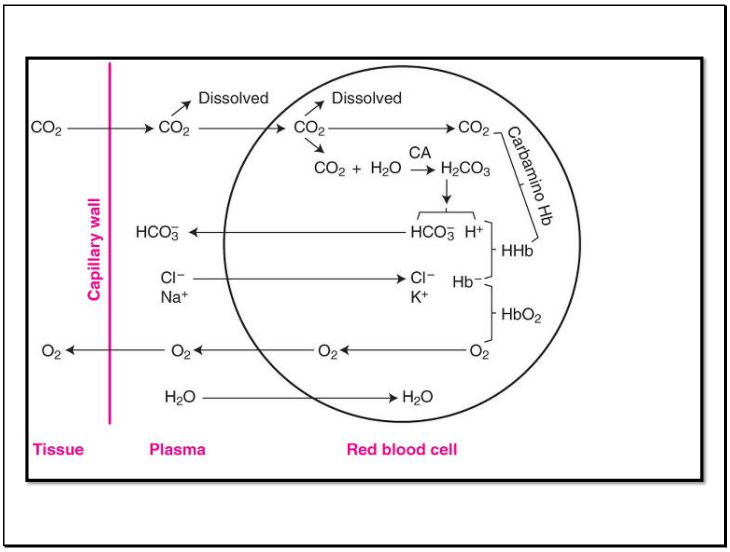

Dissolved
Dissolved
CO2
CO2
CO2
CO2
Carbamino Hb
CO2 + H2O
CA
H2CO3
Capillary wall
HCO3−
HCO3− H+
HHb
Cl−
Na+
Cl−
K+
Hb−
HbO2
O2
O2
O2
O2
H2O
H2O
Tissue
Plasma
Red blood cell

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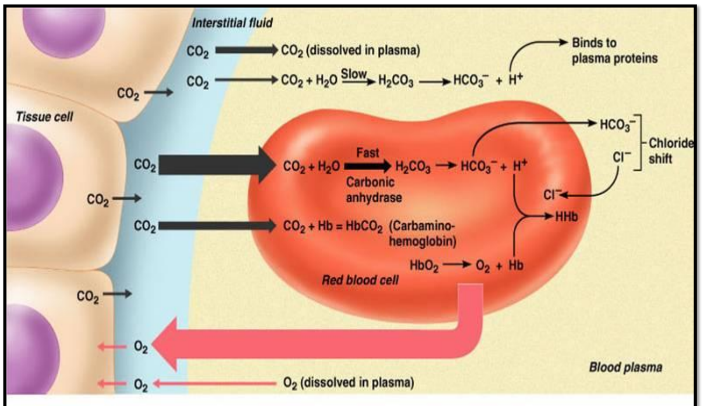

(a) Oxygen release and carbon dioxide pickup at the tissues

2) Since carbonic anhydrase enzyme is present in RBCs and absent in plasma, HCO_3^- becomes much greater in RBCs than in plasma. Therefore, bicarbonate ions diffuse from RBCs into the plasma.

3) Diffusion of HCO_3^- causes the inside of RBCs to gain a net positive charge. This attracts chloride ions from the plasma to enter RBCs in exchange using a special HCO_3^--Cl^- carrier protein in the red cell membrane.

This exchange of ions as blood moves through tissue capillaries is called **"the chloride shift"**.

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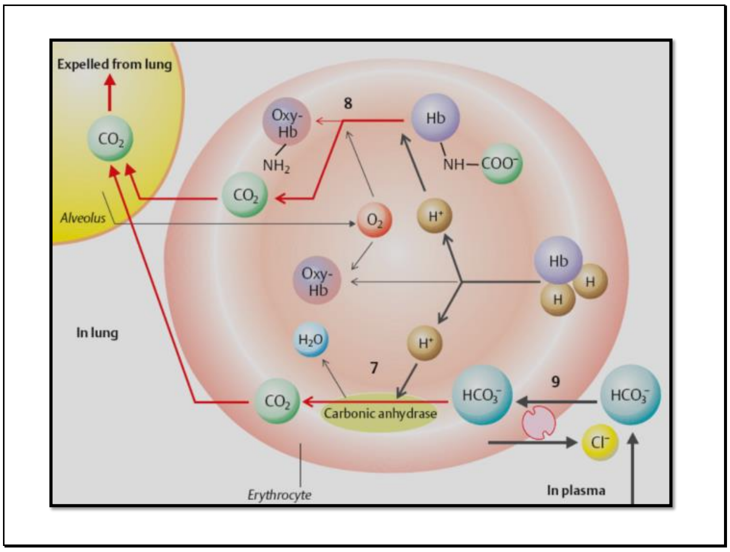

Expelled from lung
CO2
Alveolus
In lung
8
Oxy-Hb
NH2
Hb
NH—COO⁻
CO2
O2
H⁺
Oxy-Hb
Hb
H
H
H2O
H⁺
7
9
CO2
Carbonic anhydrase
HCO3⁻
HCO3⁻
Cl⁻
Erythrocyte
In plasma

At pulmonary capillaries:

- The reverse occurs when the blood reaches the pulmonary capillaries, reduced Hb is converted to Oxy Hb, so H^+ are released within the red blood cells due to decreased affinity of Oxy HB to it.

$H\,Hb + O_2$ --------------------> $HbO_2 + H^+$

- This H^+ attracts HCO_3^- from the plasma to form carbonic acid which splits by carbonic anhydrase into CO_2 and water. This decreases the HCO_3^- concentration inside RBCs causing shift of HCO_3^- form plasma to RBCs and chloride shift is reversed.

Results of chloride shift:

1) **Increased bicarbonate** content of **both plasma and RBCs**.
2) **Increased chloride** content of **RBCs** and **its decrease in plasma**.
3) **Water shift:** As a result of increased Cl^- and HCO_3^- inside RBCs, there is an increase of osmolarity which lead to shift of water from plasma to RBCs to maintain osmotic equilibrium. So, the volume of venous RBC is increased.
4) **Hematocrit value of venous blood** is about 3% **greater** than that of arterial blood due to increased RBCs volume by water shift.
5) **The osmotic fragility of the venous blood starts earlier** than the arterial blood (i.e., the venous RBCs rupture easily).

CO_2 Dissociation Curve

It is a curve plotted between CO_2 tension (mmHg) and CO_2 content in 100 ml/blood.

How to obtain this curve?

- Samples of blood are exposed to different tensions of CO_2 and the CO_2 content in each tension is determined.
- 3 types of blood samples were used:

❑ **Fully oxygenated blood** (by having enough O_2 in the tonometer to saturate the Hb completely) which resembles arterial blood.

❑ **30% reduced blood** (by filling the tonometer with O_2 enough to saturate Hb 70%) which resembles venous blood during rest.

Significance of CO_2 dissociation curve:

1) The relationship between the CO_2 content of the blood and the partial pressure of CO_2 is more linear especially in the physiological range.

2) CO_2 content of the blood depends on:

a) partial O_2 tension (PO_2) &
b) partial CO_2 tension (PCO_2)

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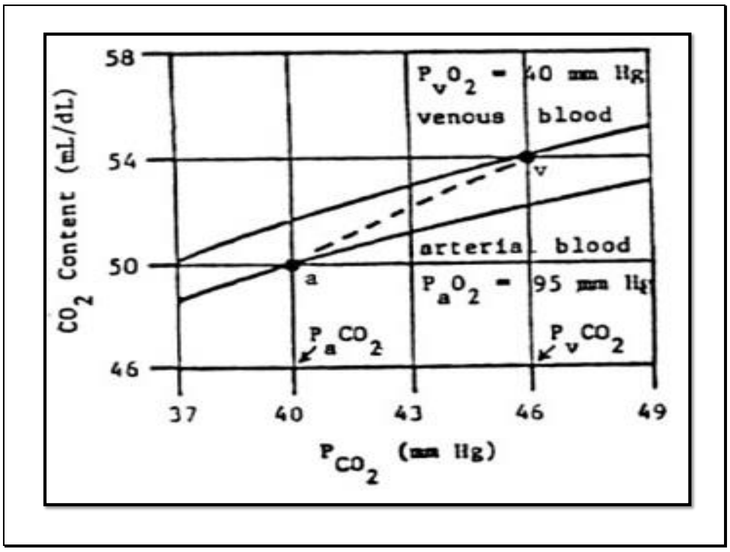

58
54
50
46
37
40
43
46
49
CO_2 Content (mL/dL)
P_{CO_2} (mm Hg)
P_vO_2 = 40 mm Hg
venous blood
v
arterial blood
a
P_aO_2 = 95 mm Hg
P_aCO_2
P_vCO_2

a) Partial O_2 tension (PO_2): The more PO_2, the less CO_2 content of the blood at a given CO_2 tension. From the curve, the fully saturated blood carries less CO_2 than the reduced Hb. This is because reduced Hb is a weaker acid than oxy HB. Therefore, reduced Hb can combine with or buffer more H^+, in turn more CO_2 can combine with the amino groups of reduced Hb.

b) Partial CO_2 tension (PCO_2): The more PCO_2, the more CO_2 content of the blood at a given O_2 tension. Increased CO_2 tension lead to increase CO_2 content since it helps Hb unloading and release of O_2 to the tissues.

3) From the curve:

- At CO_2 tension 40 mmHg, CO_2 content is 50 ml/ 100ml **(Point A).** This represents the arterial side.
- At CO_2 tension 46 mmHg, the CO_2 content is 55ml/ 100ml **(Point V)**. This represents the venous side during rest. So, The **A-V line** represents the tidal CO_2 at rest.
- **So, the line A-V represents physiological CO_2 dissociation curve.**

Respiratory Acidosis

Any cause that depresses the respiration -----> CO_2 retention (accumulation) ------> CO_2 dissolved in water -----> formation of carbonic acid resulting in ↓ pH (respiratory acidosis).

$$H_2CO_3 \text{ --------> } H^+ + HCO_3^-$$

This is compensated by excretion of excess bicarbonate in urine.

Respiratory Alkalosis

Any cause that stimulate the respiration -----> CO_2 washout ------> decreased CO_2 in the blood -----> increased pH (respiratory alkalosis)

This is compensated by decreased excretion of bicarbonate in urine.

The excess HCO_3^- will unite with H^+ ------> H_2CO_3 ------> CO_2 + Water

Respiratory Exchange Ratio

$$R = \frac{\text{Rate of carbon dioxide output}}{\text{Rate of oxygen uptake}}$$

Significance:

1- determines the type of consumed food.

- ❑ For CHO 1
- ❑ For fat 0.7

2- Determines the conversion of one type of food to another.

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