MED437
KING SAUD UNIVERSITY

437
PHYSIOLOGY TEAM

Transport Of O2 & CO2

➢ 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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Editing file

objectives:

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

- ➢ Understand the forms of oxygen transport in the blood, the importance of each.
- ➢ Differentiate between O_2 capacity, O_2 content and O_2 saturation. Describe (Oxygen- hemoglobin dissociation curve)
- ➢ Define the P_{50} and its significance.
- ➢ How DPG, temperature, H^+ ions and PCO_2 affect affinity of O_2 for hemoglobin and the physiological importance of these effects.
- ➢ Describe the three forms of carbon dioxide that are transported in the blood, and the chloride shift.

Overview

This lecture is arranged as :

1. hemoglobin and its types and relation with transfer of O_2 CO_2.
2. Transfer O_2.
3. The oxygen-haemoglobin dissociation curve.
4. Transfer CO_2.

الفرق كبير بين سلايدات الأولاد والبنات في
الترتيب والمفاهيم وطريقة العرض لأجل هذا
رتبناها على حسب ترتيب المصدر

Hemoglobin

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Oxygen molecule combines **loosely** **(weakly)** **and reversibly** **(can be absorbed)** with the heme portion of hemoglobin.

The haem part of the hemoglobin contains 4 atoms of iron, each capable of combining with a molecule of oxygen.

- How does the body make sure all the cells receive O2?

When PO2 is high, as in the pulmonary capillaries, oxygen binds with the hemoglobin.
when PO2 is low, as in the tissue capillaries, oxygen is released from the hemoglobin.

الهيموجلوبين يفك الاكسجين لما يمر بمنطقة ضغط الاكسجين فيها منخفض وبكذا تضمن أن كل الجسم يوصله الاكسجين بالكمية الكافية "سبحان الله"

Loading/Unloading depends on:

- PO2 of environment.
- Affinity between hemoglobin and O2
  أحيانا يكون خلل بالهيموجلوبين حتى لو ضغط الأكسجين كافي ما يرتبط

Oxygen-carrying capacity of blood determined by its (hemoglobin)

- If Hb below normal → Anemia
- If Hb above normal → Polycythemia

Hemoglobin production controlled by erythropoietin.
Production stimulated by PC02 delivery to kidneys.
Erythropoietin is synthesized 90% kidney 10% liver

Types of hemoglobin:

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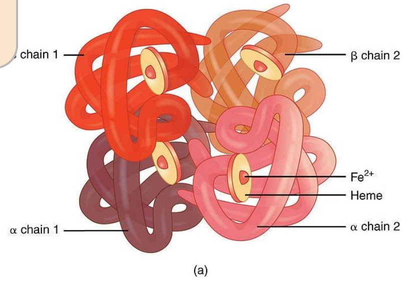
- Oxyhemoglobin:
  Normal heme contains iron in the reduced form (Fe^{2+}). Fe^{2+} shares electrons and bonds with oxygen.
  $Hb + O_2$ HbO_2
- Deoxyhemoglobin:
  When oxyhemoglobin dissociates to release oxygen, the heme iron is still in the reduced form.
- Methemoglobin:
  Has iron in the oxidized form (Fe^{3+}).
  Lacks electrons and cannot bind with 02.
  Blood normally contains a small amount.
- Carboxyhemoglobin:
  The reduced heme is combined with carbon monoxide.
  The bond with carbon monoxide is 210 times stronger than the bond with oxygen.
  Transport of 02 to tissues is impaired.

Form of O2 Transport

- 97% bound to hemoglobin (oxyhemoglobin)
- 3% dissolved in plasma



- O2 binds to the heme group on hemoglobin, with 4 oxygens /Hb
- Higher PO2 results in greater Hb saturation.
- The relation between PO2 and Hb-O2 is not linear.
  - The curve is called Oxyhemoglobin Saturation Curve.
- Which is S- shaped or sigmoid

Transport of O_2

- Transport of respiratory gases between the lungs and body tissues is the main function of blood.
- 97 % of the oxygen transported from the lungs to the tissues is carried in chemical combination with hemoglobin.
- 3 % is carried by physically being dissolved in plasma.
- **Transport of O_2 by haemoglobin:**
  - Hb combines with oxygen the compound formed is called oxyhaemoglobin.
  - The normal amount of Hb in young adults is about 14-16 gm/dl(100 ml) of the blood. Each gram of Hb can bind with 1.34 ml of O_2. Thus, if a person has a Hb is 16 gm/dl of blood his blood can carry.
  - 16 x 1.34 = 21.44 ml of O_2/dl.

Very important

- **Partial Pressure Difference:**
  - 1. High Partial Pressure of O_2 (Po_2) in **Alveoli.**
  - 2. Low Po_2 in **Capillary.**
- **Concentration Gradient:**
  - 1. High Concentration of O_2 in **Alveoli.**
  - 2. Low Concentration of O_2 in **Capillary.**

Transport of oxygen during dissolved state:

- We said before only 3% of O_2 is transported in the dissolved state. [the rest is bound to HB] [dissolved oxygen is important for areas with no blood supply e.g. the cornea and cartilage of long bone]
- At normal arterial PO_2 of 95 mmHg , about 0.29 ml of oxygen is dissolved in each 100ml of blood. [Amount of dissolved oxygen * PO_2 in arteries 0.003*95 = 0.29]
- When the PO_2 of the blood falls to 40 mmHg in tissue capillaries, only 0.12 of oxygen remains dissolved.

Obstructive [Amount of dissolved oxygen * PO_2 in venous blood 0.003*40 = 0.12]

- Therefore 0.17 ml of oxygen is normally transported in the dissolved state to the tissues per each 100ml of blood.

[Amount of dissolved oxygen at veins - amount of dissolved oxygen at arteries 0.29-0.12=0.17]

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O_2 capacity, content and saturation

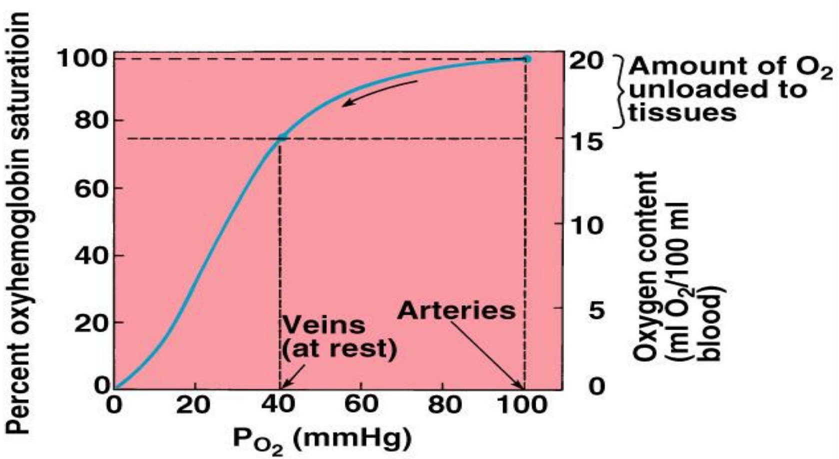
- **O_2 content:** amount of O_2 in blood (ml O_2/100 ml blood).
- **O_2-binding capacity:** maximum amount of O_2 bound to hemoglobin (ml O_2/100 ml blood) measured at 100% saturation. As we menston before 21.44ml O_2/100 ml is 100% saturation
- **Percent saturation:** % of heme groups bound to O_2.
  - **% saturation of Hb = oxygen content x100 / oxygen capacity**
- **Dissolved O_2:** Unbound O_2 in blood (ml O_2/100 ml blood).

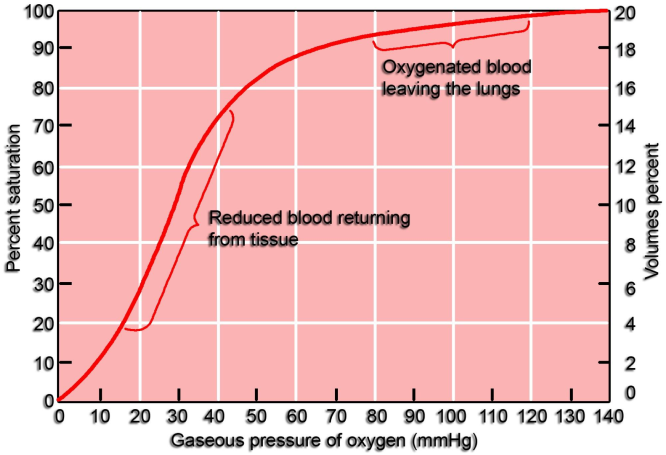
- Blood is 100% saturated with O_2: each gram of Hb carry 1.34 ml O_2. So O_2 content = 15g Hb x 1.34 O_2 = 20 ml.
- Blood is only 97% saturated -bc not all Hb types transfer O_2 - with O_2: contain 19.4 ml O_2/100 ml blood
- Amount of oxygen released from the hemoglobin to the tissues is: 5 ml O2/100 ml blood
  So O_2 content in venous blood =19.4 - 5= 14.4 ml
- During **strenuous exercise**: the oxygen uptake by the tissue increases 3 folds So 5x3 = 15 ml O_2 /100 ml blood
  So O_2 content in venous blood =19.4 -15 = 4.4 ml O_2/100 ml blood.
- At rest: tissue consume 250 ml O_2/min and produce 200 ml CO_2

The oxygen-haemoglobin dissociation curve

- It shows the progressive increase in the percentage saturation of the Hb with the increase in the PO2 in the blood
- The PO2 in the arterial blood is about 95mmHg and saturation of Hb with O2 is about 97%
- In the venous blood returning from the tissues, the PO2 is about 40 mmHg and the saturation of Hb with O2 is about 75%

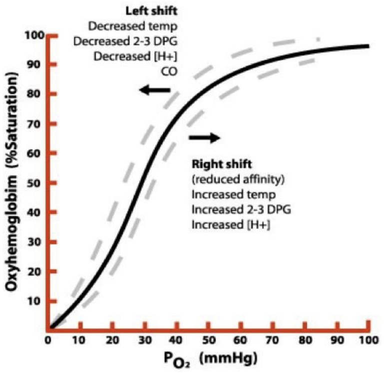
There is always a question from this slide

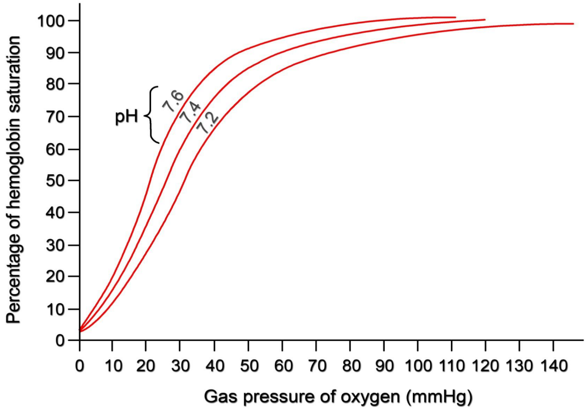




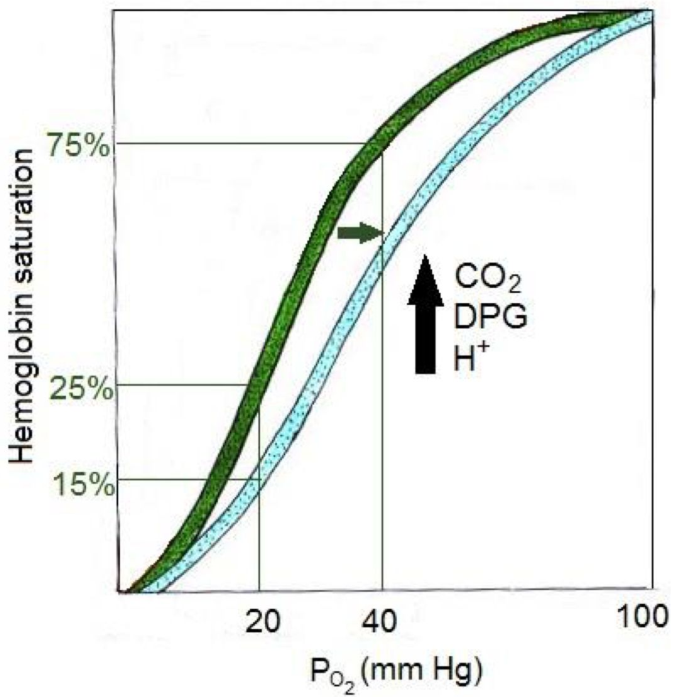
Factors shifting oxygen-haemoglobin dissociation curve to the right

1- **increased** by hydrogen ions
2- **increased** by CO_2
3- **increased** temperature
4- **increased** DPG **diphosphoglycerate**





Factors affecting oxygen-haemoglobin dissociation curve

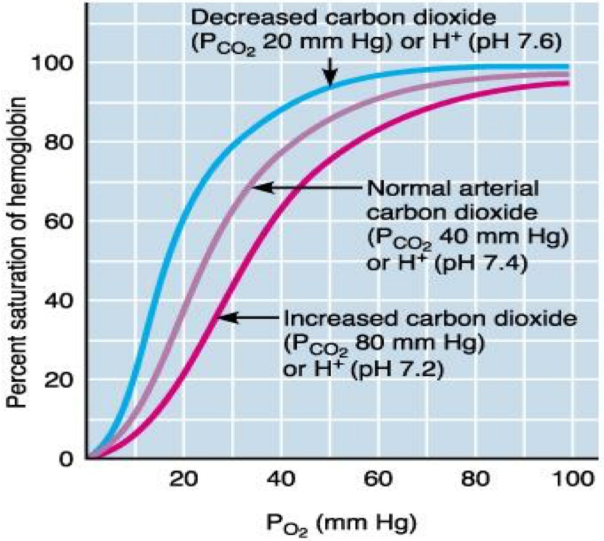


Factors affecting the affinity of Hb for O_2

4 important factors

- The ↓ pH or ↑ (H+ conc)
- The ↑ temperature
- The ↑ concentration of 2,3 **diphosphoglycerate** (2,3-DPG)
- ↑ PCO_2 concentration (Bohr effect)

→ all shift the curve to the right.



Bohr Effect

P50: it is the partial pressure of O_2 at which 50% of Hb is saturated with O_2. (Almost 30 mmhg)

↑ P50 means **right** shift → **lower** affinity for O_2 [more oxygen will be released from the tissue] [unloading]

↓ P50 means **left** shift → **higher** affinity for O_2 [more O2 will bind to the tissue][binding]

Factors Affecting Oxyhemoglobin Dissociation Curve

Table 16.9 Factors That Affect the Affinity of Hemoglobin for Oxygen and the Position of the Oxyhemoglobin Dissociation Curve

Factor	Affinity	Position of Curve	Comments
↓pH	Decreased	Shift to the right	Called the Bohr effect; increases oxygen delivery during hypercapnia
↑Temperature	Decreased	Shift to the right	Increases oxygen unloading during exercise and fever
↑2,3-DPG	Decreased	Shift to the right	Increases oxygen unloading when there is a decrease in total hemoglobin or total oxygen content; an adaptation to anemia and high-altitude living

Table 16.10 Effect of Lung Function on Blood Acid-Base Balance

Condition	pH	P_{CO_2}	Ventilation	Cause of Compensation
Normal	7.35–7.45	39–41 mmHg	Normal	Not applicable
Respiratory acidosis	Low	High	Hypoventilation	Cause of the acidosis
Respiratory alkalosis	High	Low	Hyperventilation	Cause of the alkalosis
Metabolic acidosis	Low	Low	Hyperventilation	Compensation for acidosis
Metabolic alkalosis	High	High	Hypoventilation	Compensation for alkalosis

Table 16.8 Effect of pH on Hemoglobin Affinity for Oxygen and Unloading of Oxygen to the Tissues

pH	Affinity	Arterial O_2 Content per 100 ml	Venous O_2 Content per 100 ml	O_2 Unloaded to Tissues per 100 ml
7.40	Normal	19.8 ml O_2	14.8 ml O_2	5.0 ml O_2
7.60	Increased	20.0 ml O_2	17.0 ml O_2	3.0 ml O_2
7.20	Decreased	19.2 ml O_2	12.6 ml O_2	6.6 ml O_2

The Rt and Lt shifts:

It means:
when you have less O_2 you will keep it
It means-
Increased binding capacity

Definition:

- **Rt shift** means the oxygen is unloaded to the tissues from Hb
- **Lt shift** means loading or attachment of oxygen to Hb.

- **Increased** 2,3DPG, H+, Temperature , PCO_2 shift the curve to **right.**
- **2,3DPG** : is synthesized in RBCs from the glycolytic pathway , it binds tightly to reduced Hb. **increased** 2,3 DPG facilitate the oxygen release and shifts the dissociation curve to Rt. metabolically important phosphate compound present in the blood in different concentrations under different metabolic conditions.
- **2,3 DPG** increases in the RBCs in anemia and hypoxemia,and thus serves as an important adaptive response in maintaining tissue oxygenation [facilitate release of oxygen in tissue, shifts the curve to the right] [adaptive mechanism in case of pulmonary disease or living in a high altitude]

- **Fetal Hb:** has a P50 of 20 mmHg in comparison to 27 mmHg of adult Hb. [lower because of the increased affinity to oxygen]

The right and left shifts

- Effect of increasing carbon dioxide and hydrogen ions that will shift the curve to the right on the curve (Bohr effect) it is a responsive mechanism
- At lung:
  Movement of CO_2 from blood to alveoli will decrease blood CO_2 & H+ (يطلع الأشياء الزايدة من الدم للالفولي لخارج الجسم) →shift the curve to left (يرجع شوي لليسار لأنه بالأساس مايل لليمين فيوصل للتوازن نوعا ما) & Increase O_2 affinity of Hb allowing more O_2 transport to tissues (لأننا قلنا أن من أبرز مشاكل الميلان لليمين أن الافينيتي تكون قليل لكن عند الرئة لازم تكون مرتفعة)
- At tissues:
  Increase CO_2 & H+ in blood leads to →shift the curve to right.& Decrease O_2 affinity of Hb allowing more O_2 transport to tissues

- **Shift of dissociation curve during exercise:**
- Exercise increases Temp, H+, 2,3 DPG and shift the curve to Rt.
- **Utilization coefficient**: The percentage of the blood that gives up its oxygen as it passes through the tissues capillaries.
- **Utilization Coefficient** = O_2 delivered to the tissues \ O_2 content of arterial blood
- Normally at rest = 5 ml/20 ml= 25%
- During exercise it = 15 ml/20 ml= 75 % - 85%

طيب ليش كل هذا يحدث وش الهدف؟
As the blood passes through the tissues, CO2 diffuses from the tissue cells into the blood. This diffusion increases the blood PCO2, which in turn raises the blood H2CO3(carbonic acid) and the hydrogen ion concentration.These effects shift the O2-hemoglobin dissociation curve to the right and downward, forcing O2 away from the hemoglobin and therefore delivering increased amounts of O2 to the tissues. Exactly the opposite effects occur in the lungs.

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The Haldane Effect:

- When oxygen binds with hemoglobin, carbon dioxide is released to increase CO_2 transport.
- Binding of Hb with O_2 at the lung causes the Hb to become a stronger acid, and this in turn displaces CO_2 from the blood and into the alveoli.
- Change in blood acidity during CO_2 transport .
- Arterial blood has a pH of 7.41, and the pH of venous blood (which has higher PCO_2) falls to 7.37 (i.e. change of 0.04 units takes place, because of release of CO_2).

Respiratory Exchange ratio (Respiratory Quotient):

- Normally it is 4/5= 82%
- When Carbohydrate diet is used R = 1
- When fats only is used R=0.7
- A person on normal diet R=0.825

Table 18.1 THE BASICS OF THE BOHR AND HALDANE EFFECTS

Bohr Effect	Haldane Effect
CO_2 and H^+ binding to Hb → decreased Hb affinity for O_2	Deoxygenation of Hb → increased Hb affinity for CO_2
Shifts O_2-hemoglobin curve RIGHT	Shifts CO_2-blood curve LEFT

Transport of CO_2

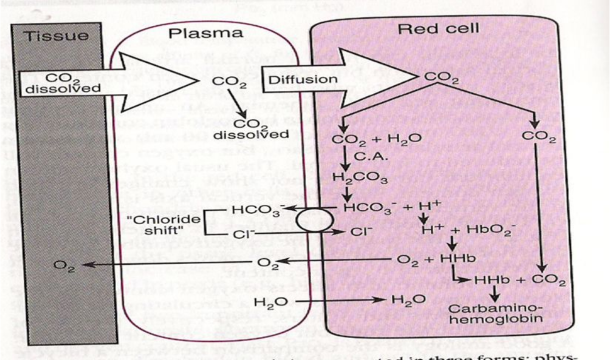
- ➢ Large amount of CO_2 is continuously produced in the body.
- ➢ Under normal resting conditions each 100 ml of deoxygenated blood contains 4 ml of CO_2 which is carried in the blood in three forms:

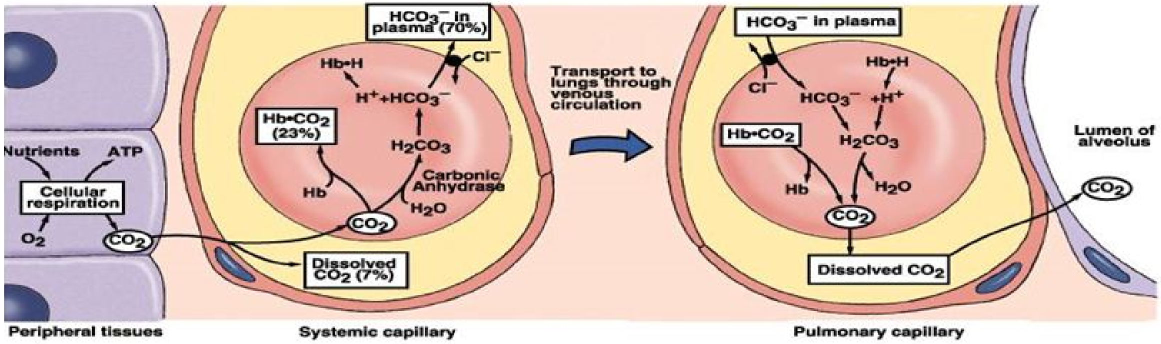
70% of CO_2 is transported in bicarbonate form	23% combines with the globin part of haemoglobin to form **carbamino haemoglobin**	7% is dissolved in plasma.
• As CO_2 diffuses into the tissue capillaries it then enters the red blood cells. • CO_2 reacts with water to form carbonic acid in the presence of carbonic anhydrase enzyme. This enzyme accelerates the reaction 4800 times more, so it occurs within a fractions of second. •The carbonic acid is then dissociated into hydrogen ions (H^+) and bicarbonate ions. • Hydrogen ions combine with haemoglobin to form H,Hb, and the bicarbonate ions (HCO_3^-) leave RBCs and enter the plasma. To maintain the negativity of RBCs, chloride ions (Cl^-) enter from the plasma into the RBCs. • The exchange of bicarbonate ions from RBCs to plasma and Cl^- ions from plasma to RBCs is called the bicarbonate chloride shift phenomenon.	• Co combines with Hb at the same point on the Hb molecule as does oxygen. • It binds with Hb about 250 times as much as O_2 (affinity of Hb to CO is very high 250 times of that to O_2). • It causes left shift of the O_2-Hb curve. [causes carbon monoxide poisoning] [we have to be very careful when using a heater because the gas is clear with no smell so we have to open the windows]	• Little CO_2 is transported in the dissolved state to the lungs. • PCO_2 of venous blood is 45 mm Hg and the PCO_2 of arterial blood is 40 mmHg. • The amount of CO_2 dissolved in the blood at 45 mmHg is 2.7 ml/dl (2.7%). The amount of CO_2 dissolved at 40 mmHg is about 2.4 ml. The difference between 2.7 and 2.4 is only 0.3 ml. • About 0.3 ml CO_2 is transported in the form of dissolved CO_2 by each 100 ml of blood. It is about 7 % of all CO_2 is transported in this form.

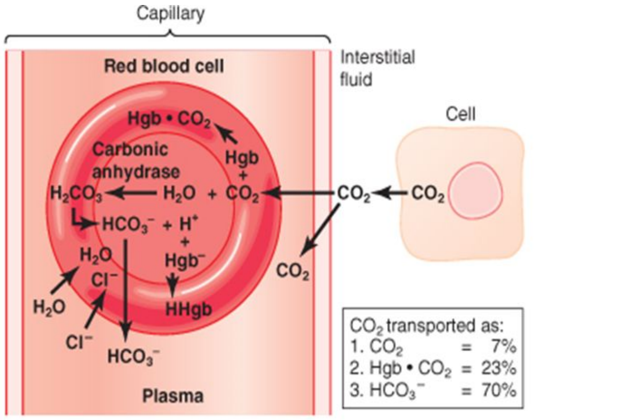
Transport Of Co2

Diffusion Effected By:

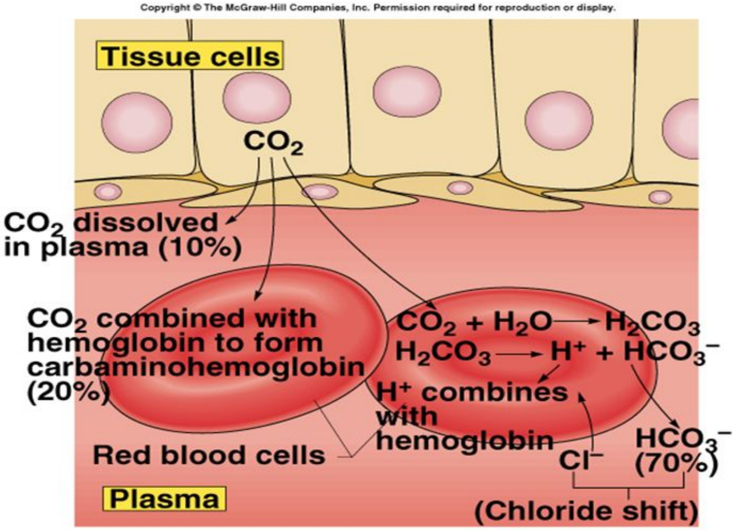
- ➢ Partial Pressure of CO_2 (Pco_2)-Higher In Tissues Than In Capillary.
- ➢ Concentration Gradient-CO_2 Higher In Tissues Than In Capillary.
- ➢ Distance-Very Short..

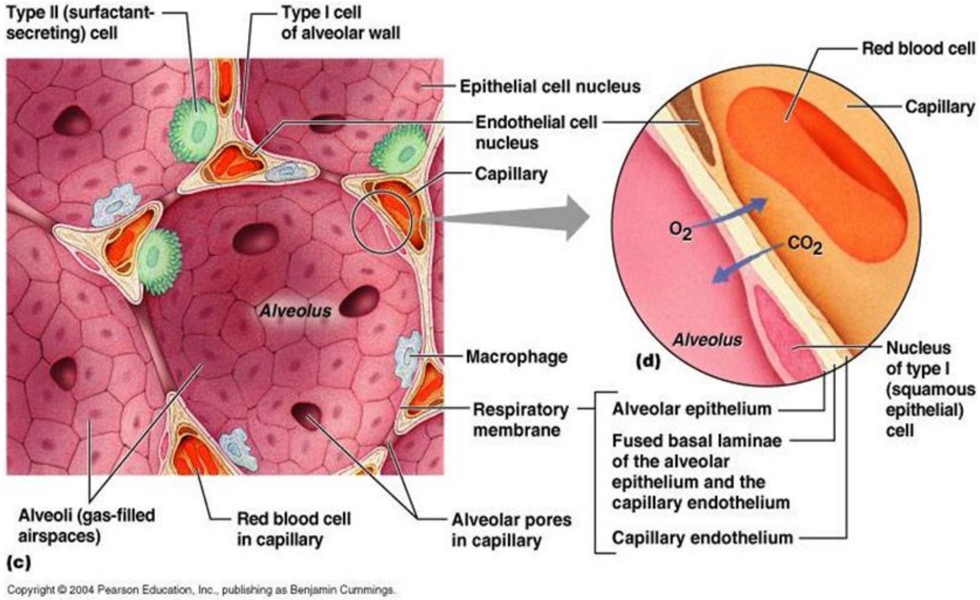




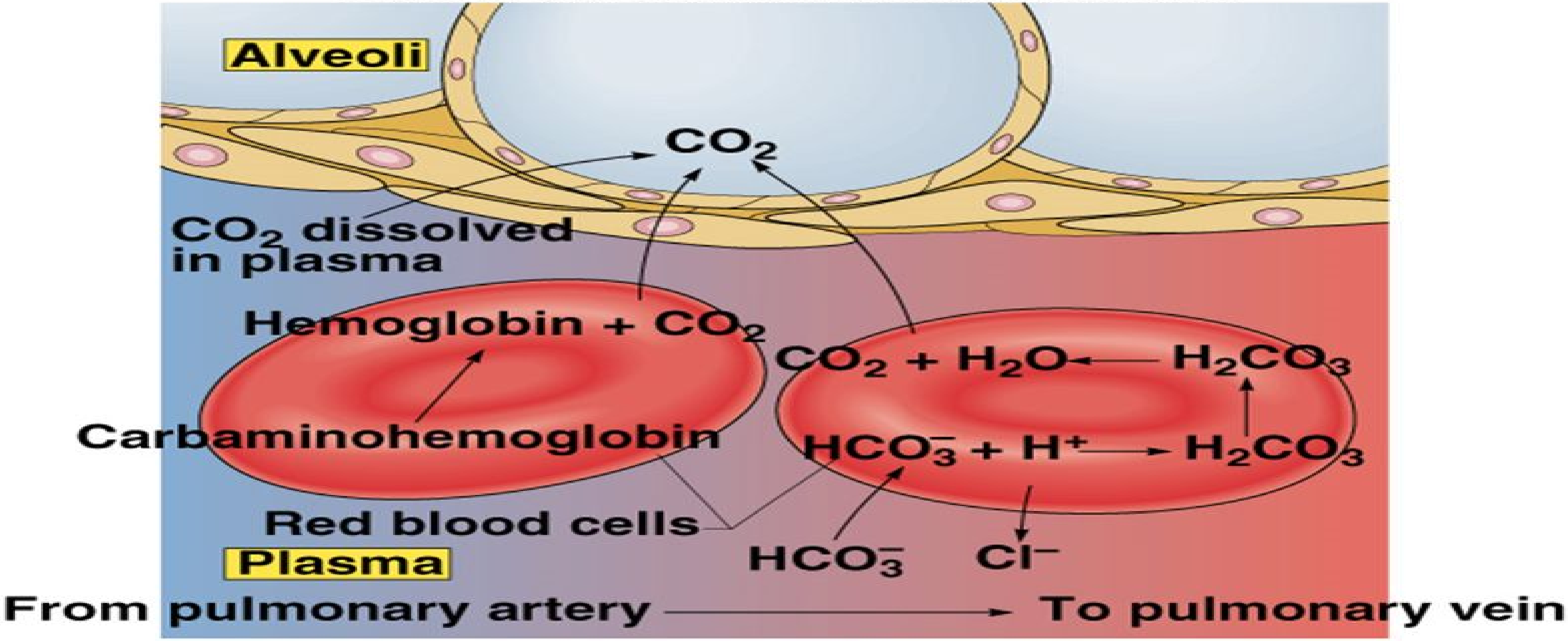


Carbon Dioxide Transport And Chloride Shift





Reverse Chloride Shift In Lungs



At Pulmonary Capillaries

- $H_2O + CO_2$ H_2CO_3 $H^+ + HCO_3^-$

At the tissue

- CO_2 diffuses into the RBC; shifts the reaction to the right.
- Increased [HCO_3^-] produced in RBC: HCO_3^- diffuses into the blood.
- RBC becomes more +.Cl^- attracted in (Cl^- shift).
- H^+ released buffered by combining with deoxyhemoglobin.
- $HbCO_2$ formed.
- Unloading of O_2.

At the alveoli

- CO_2 diffuses into the alveoli; reaction shifts to the left.
- Decreased [HCO_3^-] in RBC, HCO_3^- diffuses into the RBC.
- RBC becomes more - .
- Cl^- diffuses out (reverse Cl^- shift).
- Deoxyhemoglobin converted to oxyhemoglobin.
- Has weak affinity for H^+.
- Gives off $HbCO_2$.

Oxygen and Carbon dioxide Transport

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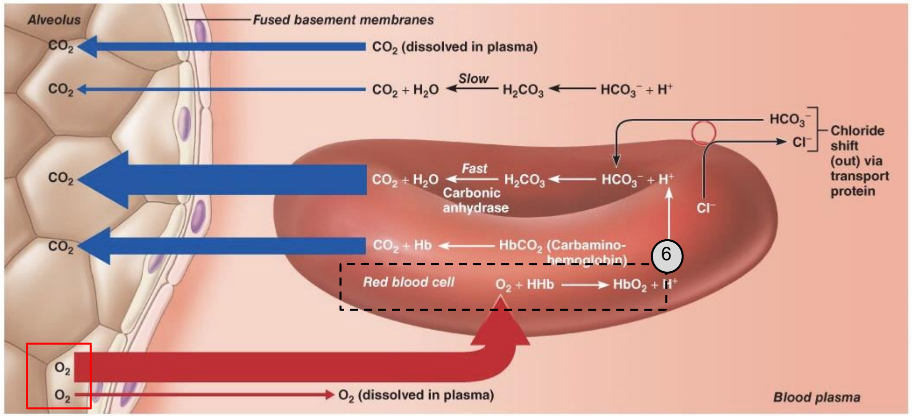
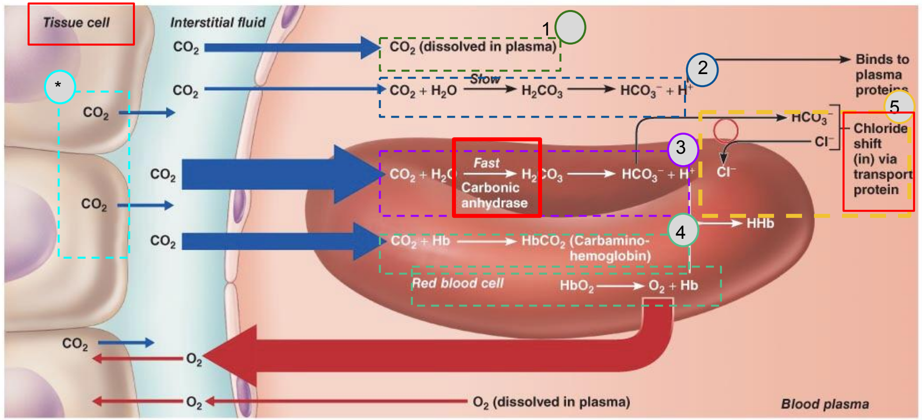


(b) Oxygen pickup and carbon dioxide release in the lungs



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

At the alveoli

Same reactions but reversed

At tissue level

CO_2 is produced in the tissue and transported through the blood.

1- 7% of the CO_2 is dissolved in plasma
2- CO_2 reacts with water in the plasma (slowly because it doesn't have enzymes) and transported as bicarbonate
3-CO_2 reacts with water in the red blood cells (fast because of the enzyme carbonic anhydrase and is converted to carbonic acid then to bicarbonate and a proton.
4-CO2 reacts with hemoglobin and becomes carbaminohemoglobin
5-to maintain electrical equilibrium, bicarbonate is removed to outside of the RBC, and chloride is moved in. this is called a chloride shift
6-oxygen binds to the heme group on the hemoglobin

Quiz

1- The percentage of the blood that gives up its oxygen as it passes through the tissues capillaries is called :

A- dissolved state

B- utilization coefficient

C- haladen effect

D- oxyhemoglobin dissociation curve

2- how many of oxygen is transported normally in dissolved state to the tissue per 100ml of blood:

A- 0.29ml

B- 0.12ml

C- 0.17ml

D- 19.4ml

3-Each 100 ml of blood carry about:

A-5 ml of CO_2 from the tissues

B-3 ml of CO_2 from the tissues

C-6 ml of CO_2 from the tissues

D-4 ml of CO_2 from the tissues

4- CO Combined with Hb causes :

A-left shift of the O_2-Hb curve.

B-right shift of the O_2-Hb curve.

C-vertical shift of the O_2-Hb curve.

D-no change in the O_2-Hb curve.

1-B
2-C
3-C
4-A

Female’s team:

Leader: Alanoud Salman Alotaiby

Members:

1- Reem ALQarni
2- fatimah albassam
3- Ahad Ahmed ALGrain.
4- Noura Alothaim
5- Sarah AlFlaij

Male’s team:

Leader: Abdulhakim AlOnaiq

Members:

Videos links:
https://www.youtube.com/watch?v=bhJarMGNFw4&index=33&list=PLTF9h-T1TcJhcNo9M1VFXz6rMKT6CM_wd